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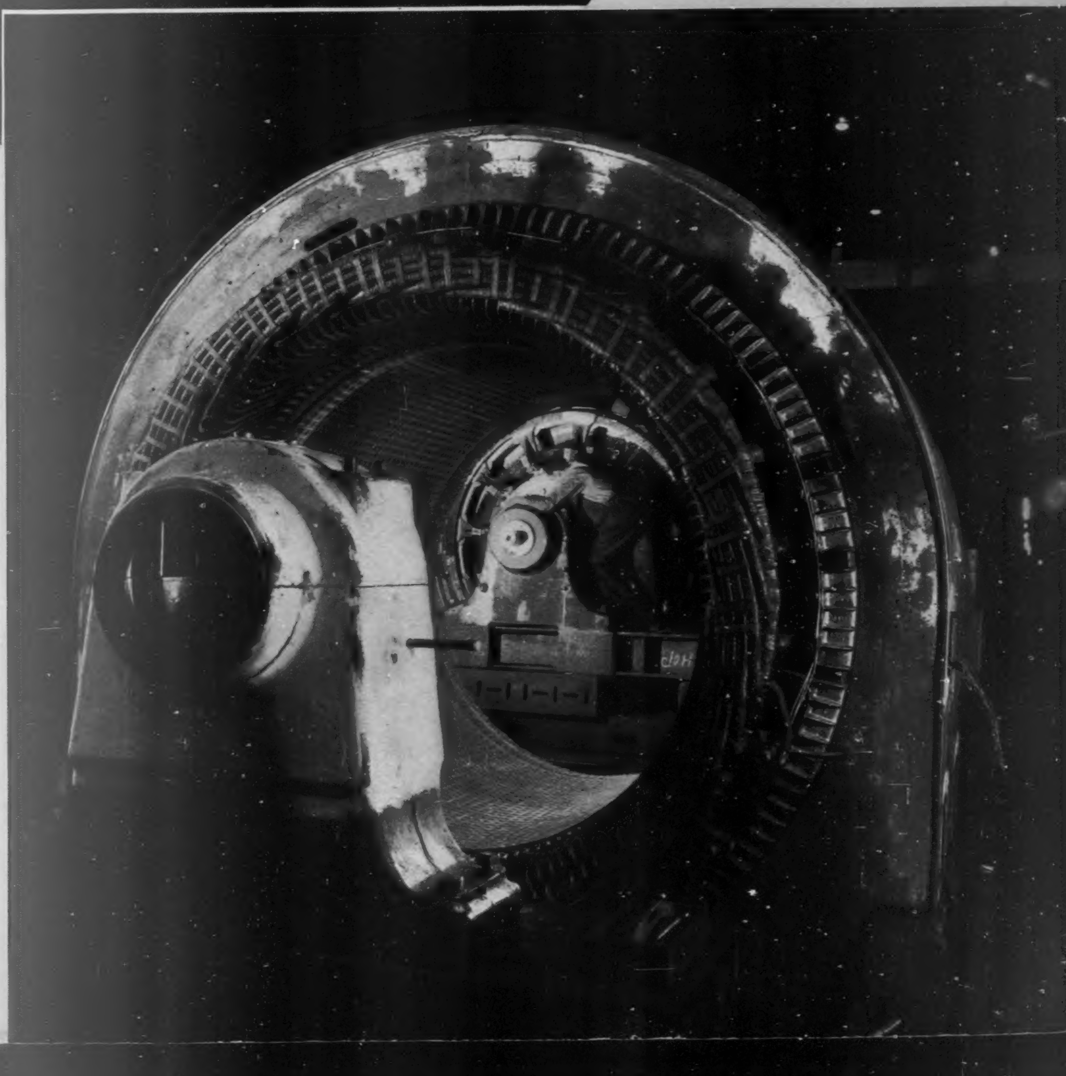
ALLIS-CHALMERS

ELECTRICAL REVIEW

March • 1938



Looking through the stator of a 3,000 kw Turbo-Generator.

ALLIS-CHALMERS ELECTRICAL REVIEW

C O N T E N T S

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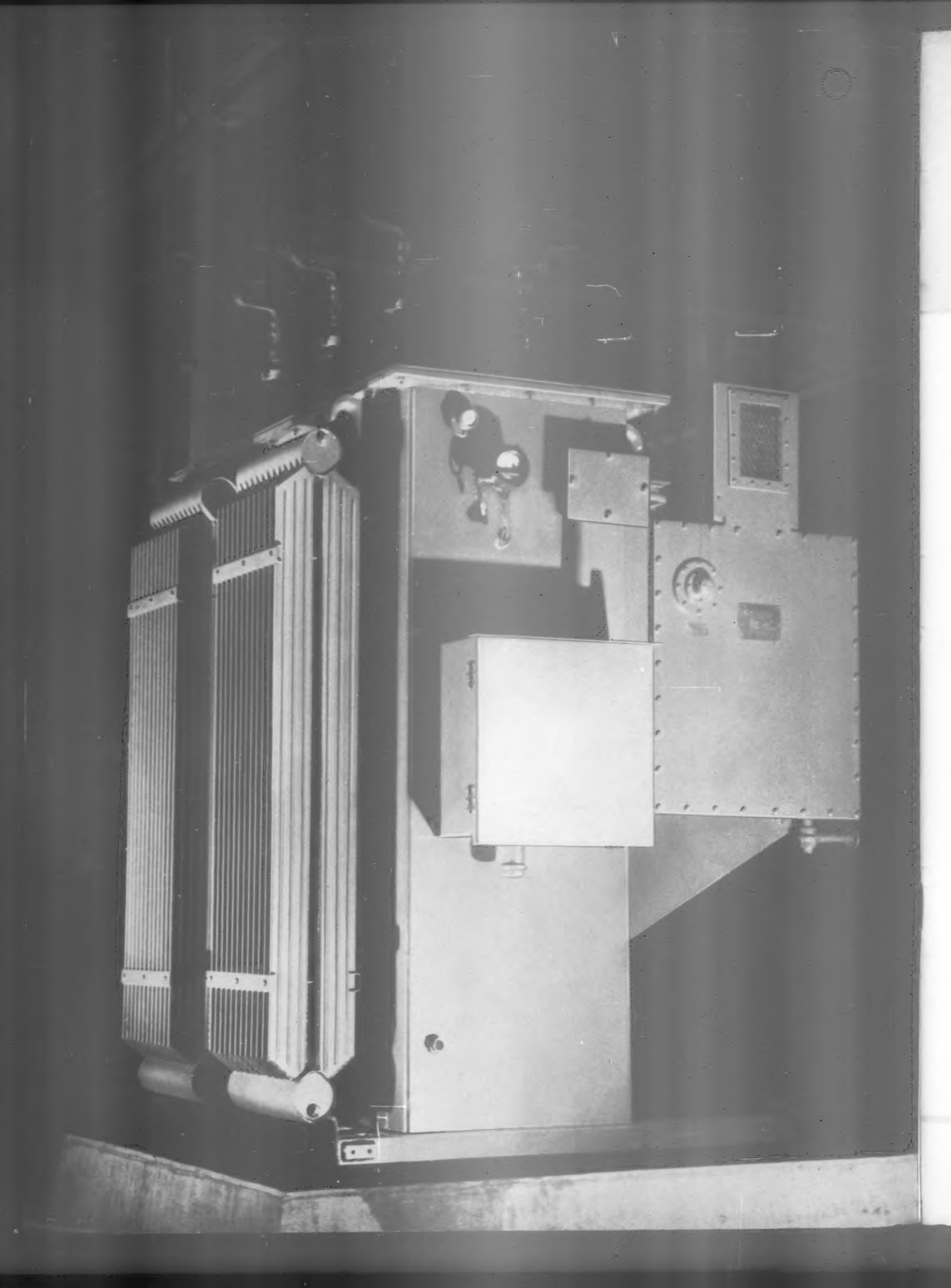

THE OPERATION OF STEP TYPE FEEDER REGULATORS

• J. I. Onarheim
TRANSFORMER DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

● Step type feeder voltage regulators have now been in service for about four years — long enough to draw some worthwhile conclusions concerning some of the design principles involved in this recent development. Large power transformers equipped with tap changing under load equipment had been in successful operation for over ten years prior to the introduction of the step voltage regulator, and naturally some of the design principles incorporated in the step voltage regulator were logical developments from experience gained with the larger and more costly tap changing equipment used with power transformers. While the step voltage regulator is primarily a transformer with tap changing under load equipment, the type of service encountered is quite different from that experienced with large power transformers.

• Size of steps

Although steps of two and one-half per cent or more were commonly provided in large power transformers equipped with tap changing under load equipment, close regulation demands much smaller steps for use in the step voltage regulator. In some applications the step voltage regulator is now used where induction regulators had heretofore been used with a primary relay setting of about plus or minus one per cent. With a relay setting of plus or minus one per cent it is evident that the two and one-half per cent steps commonly used with power transformers could not be used, but that either one and one-quarter per cent or five-eighths per cent, or thereabouts, were required. Obviously, for the same cost, five-eighths per cent steps would be preferable, provided they could be obtained without unnecessary complication, and this can be done economically with only eight taps in the transformer winding by employing a reversing switch and half-cycling operation. A review of voltage curves produced by regulators with five-eighths per cent steps (see Fig. 1) shows conclusively that the voltage curves obtained are as smooth as those produced by induction regulators with the closest possible primary relay settings.

AT LEFT: A step regulator with ⅝% half-cycling steps to give plus or minus 10% voltage regulation on a load of 3000 kva at 11500 volts in a utility outdoor sub station.

Tap changing mechanism of a 5/8% half-cycling step voltage regulator.

• Control systems

With the conventional induction regulator control equipment it is practically impossible to adjust the primary relay for closer than one per cent regulation, because the holding coil adjustment prevents a closer setting of the contacts. Therefore, a new system of control was developed that would permit primary relay adjustments as close as five-eighths of one per cent. Where the voltage on the primary relay contacts is 120, holding coils are necessary to hold the contacts firmly closed to reduce contact burning. When the contacts are not cleaned continually, they will weld closed and cause the regulator to travel to one extreme position and remain on this position until some customer com-

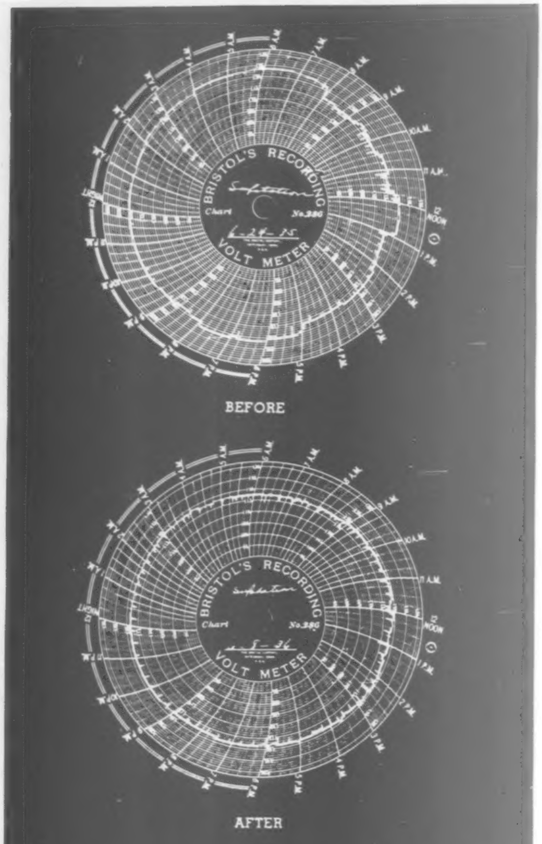

Fig. 1 — Voltage Curves produced by 5/8% Step Regulators.

plains of high or low voltage. When the power on the relay contacts is low, the holding coils can be disconnected, for with low energy the contacts will not burn and firm contact pressure is not required. A spark suppressor, or condenser, is usually connected across the relay contacts to reduce the amount of arcing still further.

Compounding coils are also required for the induction regulator control circuit to hold the contacts closed until the voltage is returned to normal. Adjusting the holding coils is a very critical operation because, if they are not set close enough, burning of the contacts will result, and if they are set too close there is the danger of "hunting." Holding or compounding coils are not required in modern step regulator control systems, so they are eliminated. Operators have found this new low energy control system to be amazingly accurate and simple to adjust.

When the tap-changer is provided with a mechanism that automatically centers the moving contacts, the brake usually required is not necessary, and consequently frequent brake adjustments are avoided.

• Time delay relay

Time delay relays were not generally used with feeder regulators until the step type regulator appeared. When induction regulators are used on circuits where the voltage is constantly fluctuating, the primary relay contacts are given wider separation in order to eliminate too frequent operations. This wider relay contact setting, of course, results in poorer voltage regulation. With a time delay relay, Fig. 2, added to the circuit, it is possible to set the relay contacts for very close regulation. As the primary relay contacts close, they excite the timer, and when the relay has been excited a predetermined time, the operating motor circuit will be closed, causing the tap changing mechanism to operate. The ideal time delay relay is one that will wind up when the relay contacts are closed and will unwind at about the same speed when the relay contacts are open. This type of relay has proved to be superior to the instantaneous reset relay for most circuits.

The curves, Fig. 3, illustrate the effect of different time delay settings for two different circuits. These curves will be different for each particular circuit, but they do illustrate the effect of time delay settings on tap changer operations. Operating engineers have experimented with various time delay settings and have kept a record of recording voltmeter curves obtained with these different settings. These experiments have, in a large majority of cases, resulted in a final setting on the time delay contactor of 50 or 60 seconds.

One operator reported eight operations per day with a time delay setting of 60 seconds and 84 operations per day with a setting of 15 seconds. As the voltage curve with 60 seconds time delay was satisfactory and practically the same as with 15 seconds time delay, the operator finally set the control


Fig. 2 — Time Delay Relay.

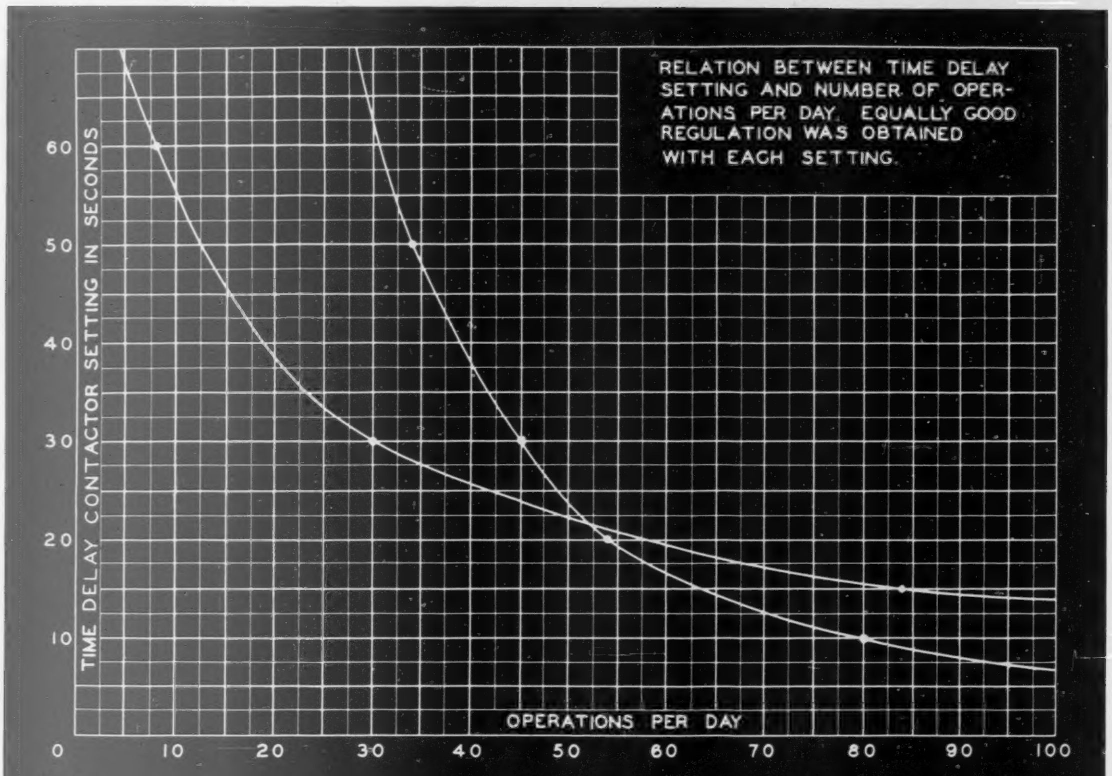

Fig. 3

for 60 seconds. On another system, 50 seconds time delay resulted in 34 regulator operations per day, and ten seconds resulted in 80 operations per day. The resultant voltage curves from these two settings were equally satisfactory, and the regulators were ultimately set for 50 seconds time delay.

An operation counter is usually provided on step type feeder regulators to record the number of operations of the tap changing mechanism. By recording the number of operations completed each month, operators are able to compare the number of operations with various time delay and voltage control relay settings.

• Tap changing contacts

The benefits to be derived from high speed contact separation have been demonstrated by the data obtained from years of service experience with oil circuit breakers. The trend for several years has been to increase contact speeds, and designers developing the modern step regulator mechanism were naturally guided by this experience. Slow contact speeds in circuit breakers result in very short contact life, and therefore it is desirable to provide high contact speed in the tap changing mechanism. With modern mechanisms, such as shown on page 5, a tap change is completed in less than two cycles, which is an average speed of 75 inches per second. Contact speed is not the only important consideration—the size and composition of contacts are equally important. In addition, the life of the insulating oil is also increased when contact speed is increased and arc resisting metals are used.

The contact material should be strong mechanically and of such size as to carry away readily the heat generated at the contact surface and should also be arc resisting to insure long life. To determine the most suitable material several alloys were tested and the results compared to the service given by hard drawn copper contacts. Certain combinations of copper and zinc gave good service. However, the more expensive metals composed of various percentages of tungsten and copper were far superior to copper. The tungsten-copper metal costs considerably more than hard-drawn copper but lasts longer in service, which justifies the additional cost; for, obviously, the cost of the contacts themselves is but a small part of the cost of taking the equipment out of service and installing new contacts. Tungsten-copper contacts were used in step regulators before they were generally used in oil circuit breakers. However, the advantages of this metal are now recognized and tungsten-copper contacts are used extensively in breakers where long contact life is essential. The tungsten-copper

contacts shown in Figure 4 were operated 2,000,000 times at a voltage and current usually encountered in the average size station type regulator. Ordinarily regulators in service average less than 50,000 tap changing operations per year.

A large number of step regulators have been in service for more than three years, some of which have completed more than 600,000 operations. This experience would indicate that tungsten-copper contacts when used in connection with high contact speeds might reasonably be expected to last from ten to 20 years.

The fact that arc resisting contact metals have shown themselves to be far superior to copper for this application is becoming increasingly recognized and has led to increased use of arc resisting metals in step regulators.

• Oil sludging

Oil oxidation and carbonization have always been important considerations in the design of load tap changers. To keep these to low values it is necessary that the arc be broken quickly. When the arc is broken slowly, oxidation and carbonization are greatly increased. This established fact, therefore, demanded a mechanism that provided high speed contact separation.

Operators have inspected transformer compartment oil after more than three years' service and found that it tested 30,000 volts, which was a higher dielectric value than when originally installed. The mechanism compartment oil in one regulator after 125,000 tap changing operations tested 28,600 volts. Because of the high speed contact separation provided, there was no appreciable carbonization of the oil to lower its dielectric value. The color of the oil at the end of three years was practically the same as when the regulator was first installed.

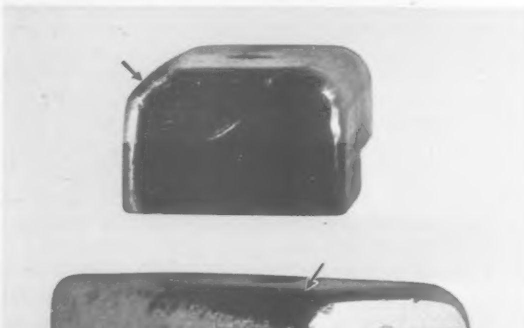

Fig. 4 — Unretouched photograph of Moving Contact, 5/8% Half-Cycling Step Regulator after life test, equal to about 2,000,000 tap changing operations; 27% at 300 volts, 90 amp; 40% at 33 volts, 164 amp; 33% at 30 volts, 136 amp.

The improvement in the dielectric value of the oil mentioned above is doubtless due largely to a unique breather principle. This breather consists of a small pipe extending from the bottom of the tank up through the oil into the air space at the top. As the air in this pipe is heated by the surrounding oil, it rises and passes over the surface of the oil and out through the top breather opening. As the air is heated, its moisture-carrying capacity increases. This type of breaker provides sufficient warm air to evaporate all moisture in the air space in the top of the case, thus preventing condensation. The small amount of moisture that may be present in oil when the transformer or regulator is first installed is gradually evaporated into the warm air and carried out through the breather.

The tap changer and transformer oil in a step regulator should be tested as often as the oil in a transformer of equivalent kva and voltage rating. Dielectric values revealed by tests covering four years' service indicate that filtering is not required any oftener than in a transformer of like size and application.

• Transformer principle superior

The transformer principle of changing feeder circuit voltages is generally recognized as superior to the induction regulator principle because of the higher efficiency, higher impulse strength, and lower costs. The only objection — that of having the voltage changes produced in steps — is eliminated when five-eighths per cent steps are provided. Another important advantage of the transformer principle is the fact that the regulator can be used on high voltage circuits without the addition of expensive insulating transformers.

Realizing that one of the principal causes for maintenance on previous regulators was the brake on the operating motor, modern regulators have been designed with self-centering tap changing mechanisms, thereby eliminating the motor brake. The original mechanism design and low energy control systems are basically unchanged. However, some minor changes have been made to provide greater convenience from the operator's point of view.

Although the step regulator was designed primarily for higher voltage circuits, its advantages have led to a rapidly increasing use on lower voltage circuits. This low voltage field was monopolized by the induction regulator formerly, but the step regulator is rapidly supplanting the older type of regulator.

The development of the step type voltage regulator solved the problem of economic voltage regulation on hundreds of circuits, and to date regulators of the design described above have been sold to regulate feeder circuits totaling more than 1,000,000 kva. Operating experience with load tap changer contacts and mechanism compartment oil has been very satisfactory when the proper alloys have been used and when high speed contact separation has been employed. The step regulator has made possible the regulation of many feeders and branches that would not have been economically feasible with the equipment available five years ago.

THE SELECTION OF ELECTRICAL DRIVES FOR PUMPS USED IN SMALL WATERWORKS

• H. A. Bartling

ELECTRICAL DEPARTMENT . . . ALLIS-CHALMERS MANUFACTURING CO.

● Electrical drives are frequently being used throughout the country for what might be called "small waterworks." These are for small towns as distinguished from the larger units used in cities. There is a need for outlining the electrical requirements for these smaller systems.

Accordingly, this article considers pumping equipments ranging from one to six million gallons per day (mgd). A total head of 200 feet has been assumed as average. With these capacities and heads the motor horsepowers are:

For pumps of one and one and one-half mgd capacity, the speed is 3600 rpm, requiring 50 and 75 hp motors respectively.

With capacities of two to six mgd, the pump speed is 1800 rpm with a corresponding horsepower range of 100 to 300.

If the total head is higher or lower than the assumed 200 foot value, the horsepower required to drive the pump varies proportionately. At larger capacities slower speed pumps should be considered.

• Synchronous or squirrel cage induction motor used as drive

For water works pumps at average heads it is not essential to vary the speed, and therefore a slip ring motor is not needed. Thus the selection of the type of motor lies between a synchronous and a squirrel cage induction motor.

For 3600 rpm pumps squirrel cage induction motors are recommended. The power factor of either a 50 hp or 75 hp motor of this type at 3600 rpm is 90 per cent or better with efficiencies of about the same value. A two-pole synchronous motor would be comparatively costly, and the efficiencies would not be much better than those of a squirrel cage motor.

The squirrel cage motor is also recommended for 1800 rpm pumps. The price of an 1800 rpm synchronous motor equipped with standard control is from 100 per cent to 25 per cent higher than for squirrel cage motors ranging from 100 to 300 hp. The higher percentage applies to the smaller rating, tapering down to the lower percentage at the larger rating. Unless provision for power factor correction is required, the use of squirrel cage motors is more economical.

In comparing synchronous or squirrel cage motors of 1800 rpm, consideration must also be given to the difference in efficiencies between the two types. The efficiency of an 80 per cent power factor synchronous motor at this speed is 0.3 or 0.4 of one per cent better than the efficiency of a squirrel cage motor at the same rating. The efficiency of a unity power factor synchronous motor at 1800 rpm averages approximately one and one-half per cent better than that of a squirrel cage motor at the same rating. This slight difference in efficiency in favor of the unity power factor synchronous motor is hardly sufficient to offset the higher first cost.

Squirrel cage motors do not require the separate excitation which must be furnished with the synchronous machine. This excitation is ordinarily provided by means of a direct-connected exciter, the cost of which has been included in the above-mentioned percentage price difference between synchronous and squirrel cage motors at 1800 rpm.

• Selection of voltage

Standard voltages adopted by electrical manufacturers are 220, 440, 550, 2200, 2300 and 4000, and will cover the ratings under consideration. For squirrel cage motors up to and including 200 hp, a 2200 volt machine costs no more than a 440 volt motor. For ratings of 100 to 200 hp, a 2200 volt motor with standard control costs from 40 per cent to 15 per cent more than a 440 volt machine. Above 200 hp the difference in control constitutes the only difference in price, as the price of the motor alone is the same for either 440 or 2200 volts. In many cases a 440 volt control at the larger ratings is more expensive than the 2200 volt control.

With synchronous motors above 75 hp, the motor price is the same for either 440 or 2200 volts. The control price varies in accordance with the condition mentioned for the squirrel cage motor.

The use of 4000 volts is not advocated, but in exceptional cases where existing conditions make it expedient to specify 4000 volt motors, the minimum rating recommended is 75 hp. For squirrel cage motors of 100 to 200 hp ratings the price above that of the 2200 volt machine varies between 40 per cent and 20 per cent. The cost of the control is also materially higher for 4000 volts.

The final selection of the voltage for the motors depends upon the voltage available from the power company's lines. It is assumed that the incoming line voltage of the power company's system is such as to require the use of a step-down transformer for any voltage of 2200 volts or below. Where a single motor is to be installed, either 440 or 2200

volts may be selected irrespective of the cost, depending upon local conditions. With the single motor in large ratings it might prove expedient, in order to reduce copper in leads to the motor, to use a 2200 volt machine.

If there are other motors in the same station, it might be more economical to provide a transformer with a suitable ratio to transform to a lower voltage so that all motors may be operated from the one transformer rather than to use a 2200 volt motor and step down to a lower voltage for smaller ratings. For the majority of cases, either 440 or 2200 volt motors are best suited.

• Factors influencing choice of motor

In making a selection between squirrel cage and synchronous motors, the power factor of the respective machines is also a factor. The power factor of a 3600 rpm squirrel cage motor is approximately 90 per cent or better, and for the 1800 rpm machines, about 92 per cent. It is well known that if a squirrel cage motor is only partially loaded, its power factor is materially decreased. Since the pump load for the water works stations of the sizes being considered is such that the motors are either operating at full load or shut down, it is necessary to consider only the full load power factor of the motor. In selecting the motor rating for the pump, care should be exercised to select a rating as close to the actual pump brake horsepower as possible. Most cases do not require a motor having overload capacity for pump drive, since all general purpose motors have the well known 15 per cent service factor.

If the pumping unit is installed in a plant where it is necessary to provide corrective effect for the lagging power factor of other motors in that station, the use of synchronous motors may be advisable. The actual selection to a large extent is dependent upon the clause included in the power company's contract relative to the charge made for low power factor. At the present time the usual power contract rate is based on two charges: one, a maximum load or demand charge based on a flat rate per kw of maximum load per month; two, the rate of energy charge or load charge, which is a given amount per kilowatthour. The penalty for lower power factor therefore applies only to the maximum load charge portion of the total bill. Since the price of the 1800 rpm synchronous motor is naturally higher than that of the squirrel cage motor, it can be shown on any particular installation that even if corrective effect is required it is more economical to use a squirrel cage motor as a pump driver and provide the power factor correction by other means. To determine which is preferable for a specific installation, a careful check of the cost of each type of machine should be compared with the saving, if any, in the total power bill which can be made by raising the plant power factor.

• Starting current important

Before issuing specifications on a contemplated installation, it is well to obtain from the power company a statement of the maximum starting current which will be permitted on its lines. It is assumed that the cost of the synchronous motor will eliminate it from use on the 1800 and 3600 rpm pumps.

For squirrel cage motors up to 300 hp at 440 volts, the starting current is approximately 750 per cent for Class "A" and 550 per cent for Class "B" motors. Class "A" refers to the N. E. M. A. classification for a normal torque and normal starting current motor, and Class "B" is the N. E. M. A. classification for a normal torque and low starting current motor. The Class "B" motor is more expensive than the Class "A." For 2200 volt motors, starting currents are 800 per cent for Class "A" machines and 600 per cent for Class "B" machines. The percentages given are on the basis of 100 per cent as the normal full load current. If the power company does not permit a starting current of 550 or 600 per cent, which may be obtained from the Class "B" motors, reduced voltage starting of some means is necessary. If reduced voltage is required, Class "A" motors should be used, since they are lower in price, unless the current limitation given by the power company is so low as to make it difficult to meet its limitation by means of a single step control.

If the Class "A" motor requiring 750 per cent starting current at full voltage is purchased, a single step control will probably reduce the initial current from the line to about 300 per cent. Usually this is acceptable to the power company, but occasionally it has been found that the limitations set are extremely low. To meet these very rigid requirements, additional steps on the control are required, materially increasing the cost. Although it is difficult to give a percentage increase in cost for an additional number of steps, a rough approximation is that the standard control of one step is increased in price by 100 per cent for a two-step control.

If the starting current limitation set up by the power company requires the purchase of a two or more step control, it is necessary for the manufacturer to know the permissible increment per step. This increment is not always the same value as the initial block of current permitted by the power company.

Ordinarily the standard reduced voltage will be acceptable to the power company. It is to be noted that by using a Class "B" motor where the full voltage starting current is 200 per cent less than on the Class "A" machine, another means of meeting low starting current requirements of the power company is available without increasing the number of steps on the control.

AT RIGHT: Three centrifugal pumps with a total capacity of 1450 gpm at an average head of 225 ft installed in a southwestern municipal water plant. Driven by induction motors.


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The selection of full voltage starting or reduced voltage starting will depend largely upon the starting current limitations set up by the power company. In some locations the power companies will undoubtedly permit full voltage starting, but in others, because of loads on their lines, or for other reasons, will insist on lower starting current values, which necessitate the use of some type of reduced voltage starting equipment.

• Types of control used

Whether magnetic control or manual control is to be used will depend somewhat on the proposed installation. Manually-operated control equipment may well be used if an operator is always available or on duty at the station. The cost of manual control equipment is approximately 50 per cent of the cost of a full magnetic control. If the station is to be an isolated one where the operator will make one or two inspections daily or weekly, automatic control should be used irrespective of its cost; but if an operator is always required at the plant, then manual control should be given serious consideration.

The price of manually-operated reduced voltage control equipment will be approximately ten to 15 per cent of the combined pumping unit total price. With magnetic control equipment the control percentage of the total price increases 25 to 35 per cent.

The magnetic control is usually governed from a pressure or altitude switch. The motor will then be connected to the line in case the pressure in the water main drops to a low value and will be disconnected after this pressure is built up to a predetermined value. Even with manual control, it would probably be well to provide a connection to the manual control so that the motor will be disconnected from the line in case the pressure in the water main becomes too high. This is a safety measure and applies especially to overhead tank installations.

Some attention has been given in recent years to enclosed control. There are many types of enclosures for control equipment, varying widely in price.

It is possible to obtain a sheet metal enclosure for the standard control which has been referred to previously. With this type of enclosure, the standard panel is used and mounted inside the enclosure without any special protective devices. This light enclosure adds ten to 25 per cent to the price of standard control.

A cubicle type of control is being used extensively at the present time. A cubicle is an indoor stationary metal-enclosed structure providing mounting accommodations and containing the switching, protective, indicating and metering equipment. It provides complete isolation of high potential circuits from the low potential circuits. The primary switching devices, such as oil circuit breakers and busses, are bolted in place and located inside the enclosure. Cubicles can be relatively inexpensive, with only a minimum amount

Three centrifugal pumps with a total capacity of 13,500 gpm at a head of 290 ft, driven by 400 hp motors, for a western municipality.

of safety features, or many desirable safety features can be included, which, naturally, increase the price.

It is difficult to compare the price of a cubicle with that of standard control, because so many additions may be added to the cubicle type control. By adding all the protective devices in a cubicle control, the cost will closely approach a metal-clad unit. It is therefore desirable that a decision should be reached as to the amount of safety features required on the control.

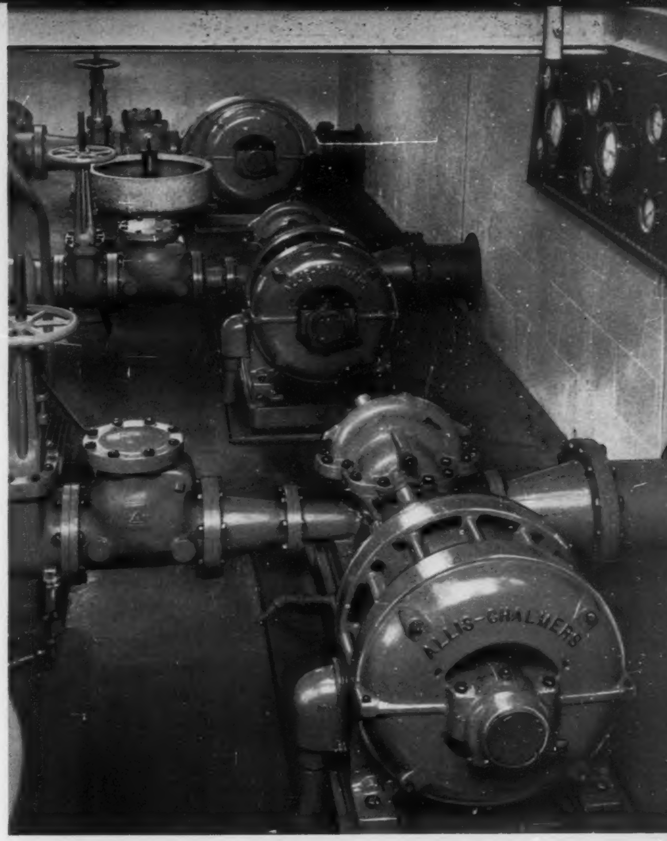
A typical metal-clad unit consists essentially of two structures—a stationary structure and a removable structure. The stationary structure includes the primary busses, instrument transformers, cable wiping sleeves for receiving incoming or outgoing cable, and the necessary instruments and relays. The removable structure consists only of the oil circuit breaker element. Provisions are made between the stationary and removable element for disconnecting both primary and secondary connections. The metal-clad control is the most expensive of the three, and in many cases will be from five to ten times the cost of the open standard control.

The selection of enclosed control will depend somewhat on the service intended for the proposed station. If it is an isolated unit, not open to the public, enclosed control would probably not be necessary. If it is a "show" station, where many inexperienced people would be likely to come in close proximity to the panel, it would be well to provide some enclosure for protection and to afford a more pleasing appearance. The item of cost would also enter into the decision. If the enclosed control is required, it is suggested that information be obtained from some manufacturer before specifications are issued.

• Pumps of larger capacities

Pumps having larger capacities than mentioned in the first paragraph will have speeds of 1200 rpm or lower. For these units the synchronous motor is to be preferred for the following reasons: the cost of the synchronous motor is comparable or less than that of a cage motor, and the synchronous motor is more efficient; a synchronous machine operates at unity power factor, or, if corrective effective is required, can operate at any leading power factor.

The remarks made relative to the starting current limitations set up by the power companies also apply to the synchronous machines. The standard torques which have been adopted by N. E. M. A. for synchronous motors are adequate in the greater number of cases. If low speed units are considered, that is, 450 rpm or lower, some attention should be given to the pull-in torque specified for the synchonous motor. If the pump must start with the discharge valve open, or with a check valve in the discharge, a pull-in torque of at least 100 per cent should be specified for the low speed synchronous motor. If the pump will always be started with the discharge valve closed until after the motor is synchronized on the line, a lower pull-in torque resulting in a lower motor price is permissible. The high pull-in torque is to be preferred for pump service.



Three centrifugal pumps with a total capacity of 4800 gpm at a head of 190 ft in a midwestern municipal water plant.

• Factors to be considered before selecting equipment

In selecting equipment for a proposed station, the following factors should, therefore, be considered before specifications are issued:

1. Type of motor, whether squirrel cage or synchronous motor, with the squirrel cage machine preferred at 3600 and 1800 rpm.

2. Voltage, which depends upon plant conditions and the power company's system.

3. Starting current limitation as imposed by the power company. If this value is exceptionally low, a statement from the power company as to the peaks which will be permitted per step should also be obtained.

4. Control, whether manual or magnetic, open or enclosed, reduced voltage or full voltage, and a statement of interrupting capacity required for the oil circuit breaker.

PERFORMANCE REQUIREMENTS OF HYDRO-ELECTRIC UNITS

• Arnold Pfau
HYDRAULIC DEPARTMENT . . . ALLIS-CHALMERS MANUFACTURING CO.

● The most efficient performance of a hydro-electric unit is obtained when the unit produces the maximum number of kilowatthours at the normal cycles or speed under the net head and quantity of water available during the periods of required operation. Three factors are involved in this performance — high efficiency, minimum outage, and minimum maintenance. (These three factors apply to the entire hydro-electric unit including the turbine, generator, and auxiliaries.)

Since the turbine is the prime mover of the unit, its performance forms the basis for the commercial success of the enterprise. Detailed attention should, therefore, be given to the design and selection of all the prime mover parts as well as the complete machine.

• Three inseparable factors

The three factors of high efficiency, minimum outage, and minimum maintenance are inseparably interlinked. For instance, a gain of two per cent in average efficiency is entirely offset by an outage of two per cent. It would be inadvisable to choose a design of turbine resulting in an improvement of two per cent in the average efficiency, if, for example, pitting of the runner or other turbine parts would involve a shut-down of such duration as to reduce the revenue of the unit two per cent.

Likewise, if in an attempt to keep the initial cost of the unit low, a design or setting of the turbine is accepted which results in frequent outages, loss of time due to time for repairs and high repair costs, the total expenditure incurred by such inefficient performance will obviously exceed that made for an initially higher priced unit with a setting properly designed to meet the conditions of operation encountered. It is therefore evident that all possible attention must be given to the quality of design materials and workmanship, and this need becomes more and more imperative, as the capacities of the units increase. A shut-down of five hours, for example, of an 80,000 kw generating unit involves a revenue loss, based upon a revenue value of two-tenths of a cent per kilowatthour, of $5 \times 0.002 \times 80{,}000$, or $800.00. Capitalized at ten per cent, this would represent an investment of $8,000.00. Therefore, an expenditure of $8,000.00 more, either initially in the purchase of equipment or later during its life, would be commercially justified, if the outage could be avoided thereby.

It is evident, too, that joint consideration of all factors involved in the selection of the most suitable and economical layout is of importance. It would not do to select each element independently of the others. Often by compromise or sacrifice of some advantage of one constituent part, more can be gained with another constituent part. The most desirable speed of a generator for economical or efficient design may involve a hydraulic end which more than offsets the benefits to be derived from the electrical end.

The first item, involving the question of turbine efficiency proper, is of a complex nature. If the load demand were constant, and also the available head and quantity of water, the problem would reduce itself to the simple requirement that the turbine be designed for maximum efficiency at these steady conditions. When load demand, available head, and quantity of water vary, it is necessary to integrate in proper relation the various values of the three factors and choose a design which assures the maximum average efficiency. Again, the variation of any of these three quantities may be periodic, seasonal, gradual, or sudden. This justifies a classification of hydro-electric units from a point of view of the nature of service demand, and brings about the following groupings:

Use of prime power

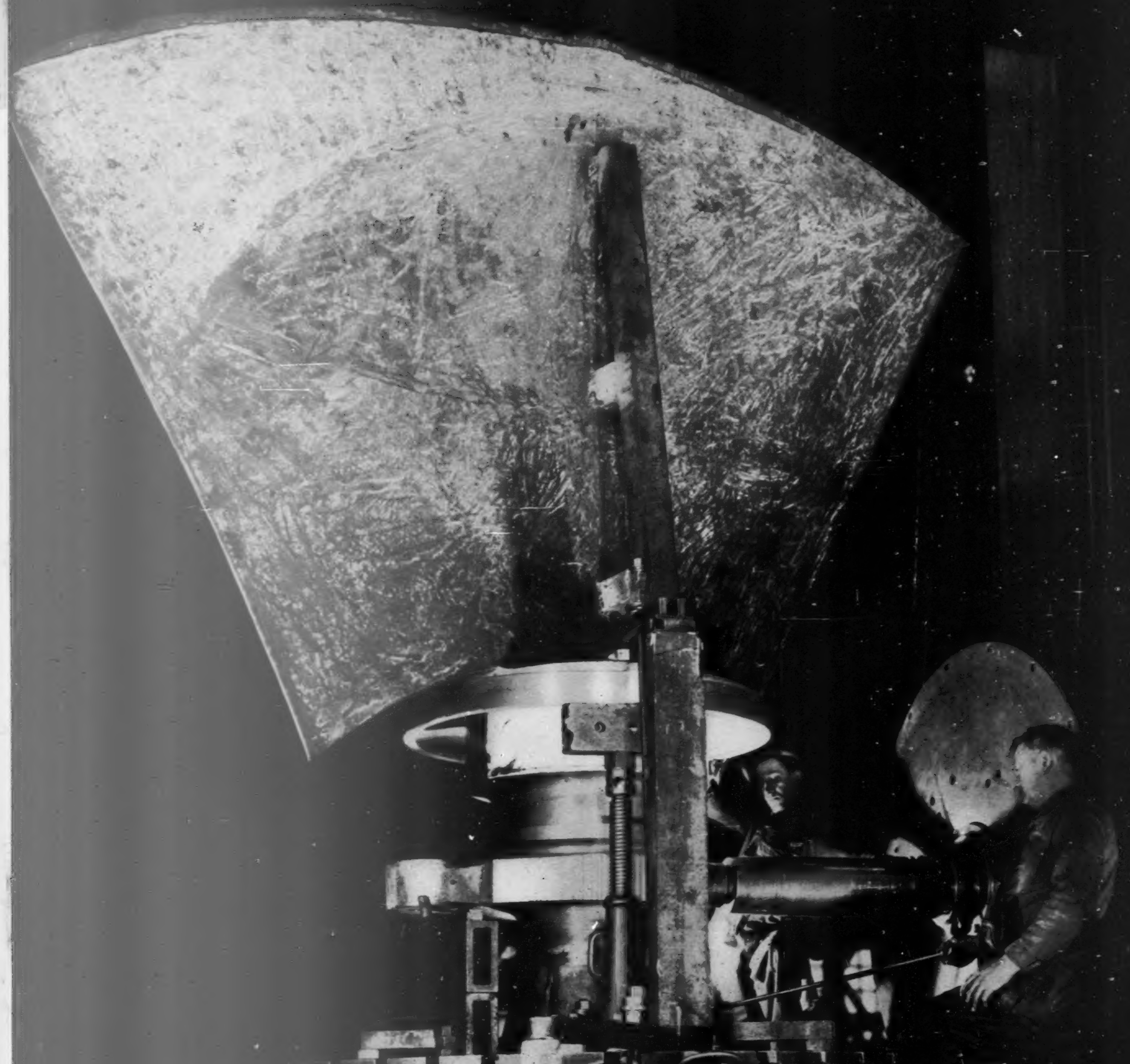
General power demand

Stand-by service

• Prime power

Naturally the rates secured for prime power are the highest. The question of maximum kilowatthours obtainable from the available head and quantity of water is predominant. This necessitates a consideration of the highest overall efficiency from an engineering point of view, but also involves the

AT RIGHT: Close-up, taken in the shop, of a milling operation on one of the runner blades of a 55000 horsepower automatic adjustable propeller blade type hydraulic turbine.



question of outage—in other words, quality. Where such units can be tied into a large power system, they can be operated on so-called "block-load" at the highest efficiency point of the turbine.

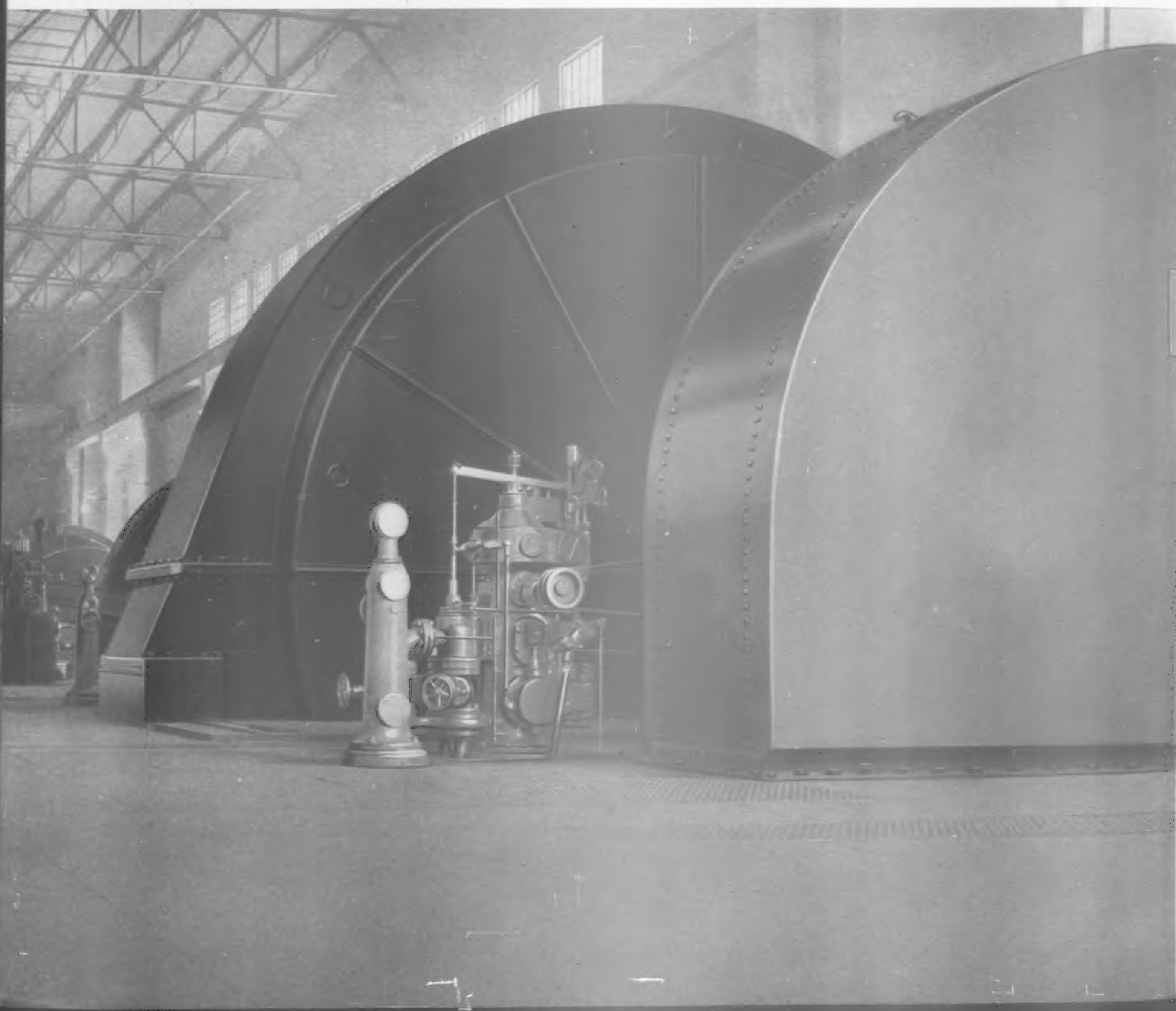
With this arrangement the governor of the turbine is provided with a load limiting device, which, on a speed or cycle drop of the system, prevents the governor from opening the turbine gates beyond the desired kilowatt output of the unit, namely, that at which the efficiency would drop to an undesirably low value, or cause overloading of the generator, particularly if, during such periods of overload, the power factor of the generator drops and would involve too high a kva output.

Similarly, if other units of the system can take care of a decrease in load demand, a so-called anti-load limiting device can be provided which, on a reduced load demand of the system (noon hour load, etc.), would prevent the governor from reducing the gate opening of the turbine to such an extent as to involve again an undesirably low efficiency of the turbine. Provision must be made in connection with such a device so that it is released if the generator becomes disconnected from the system, thereby preventing the possibility of a runaway of the unit.

• General power demand

Units suitable for such service are subjected to loads which vary either gradually or suddenly. Since the character of such service does not permit

BELOW: Alternator driven by the largest physical size hydraulic impulse turbine in the world, installed in a power plant on the Pacific Coast, rating 25,000 kva, 6900 volts.



arriving at a fixed, predominating, average load demand, it is useless under these conditions to design the turbine for highest efficiency at a fixed point. Therefore, a best average efficiency between approximate practical limits is all that can be chosen. In such a case the question of outage and repair costs becomes of greater importance. This may be termed "mechanical reliability," which involves not only the turbine proper but also its governor and auxiliaries. The flywheel effect of rotating parts of the unit, as well as the character of the load to be carried, the size of the power system with which the unit is paralleled, etc., must be known to successfully coordinate all elements.

• Stand-by service

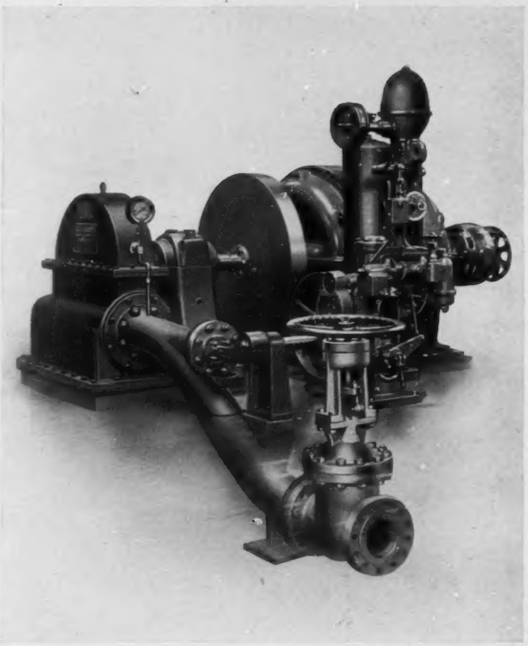
Such service is distinctly separated into two groups, involving units, either (1) periodically shut down and started when needed, or (2) operating at all times, either idling or carrying loads.

The first group requires units of the same class as those suitable for general power demand. They must be mechanically reliable and, in addition, must be provided with control equipment which permits quick starting. This requirement has been met most successfully with automatic controls for opening the gate valve, releasing the brakes on the generator, admitting oil pressure to the governor, releasing the gate latch on the turbine, opening the turbine gates to a point where the unit assumes speed, paralleling the generator with the line, and opening turbine gates to produce the desired kw output required.

The second group should preferably be equipped like the first, but, in addition, special provision must be made for running idle. This involves special designing to minimize water leakage past the guide vanes in the closed position, lubrication of water seals otherwise lubricated when the turbine operates under load, proper venting of the discharge portion below the runner, or special provision to prevent the tailwater from rising into the runner and causing churning. Additional special features are involved when the unit is to operate as a synchronous condenser floating on the line without requiring the generator to be motored, but requiring a turbine output just sufficient to maintain the synchronous speed of the unit.

• Careful analyzation important

It is obvious that for the selection of the proper design of a hydro-electric unit it is necessary to know fully all the requirements of service to be

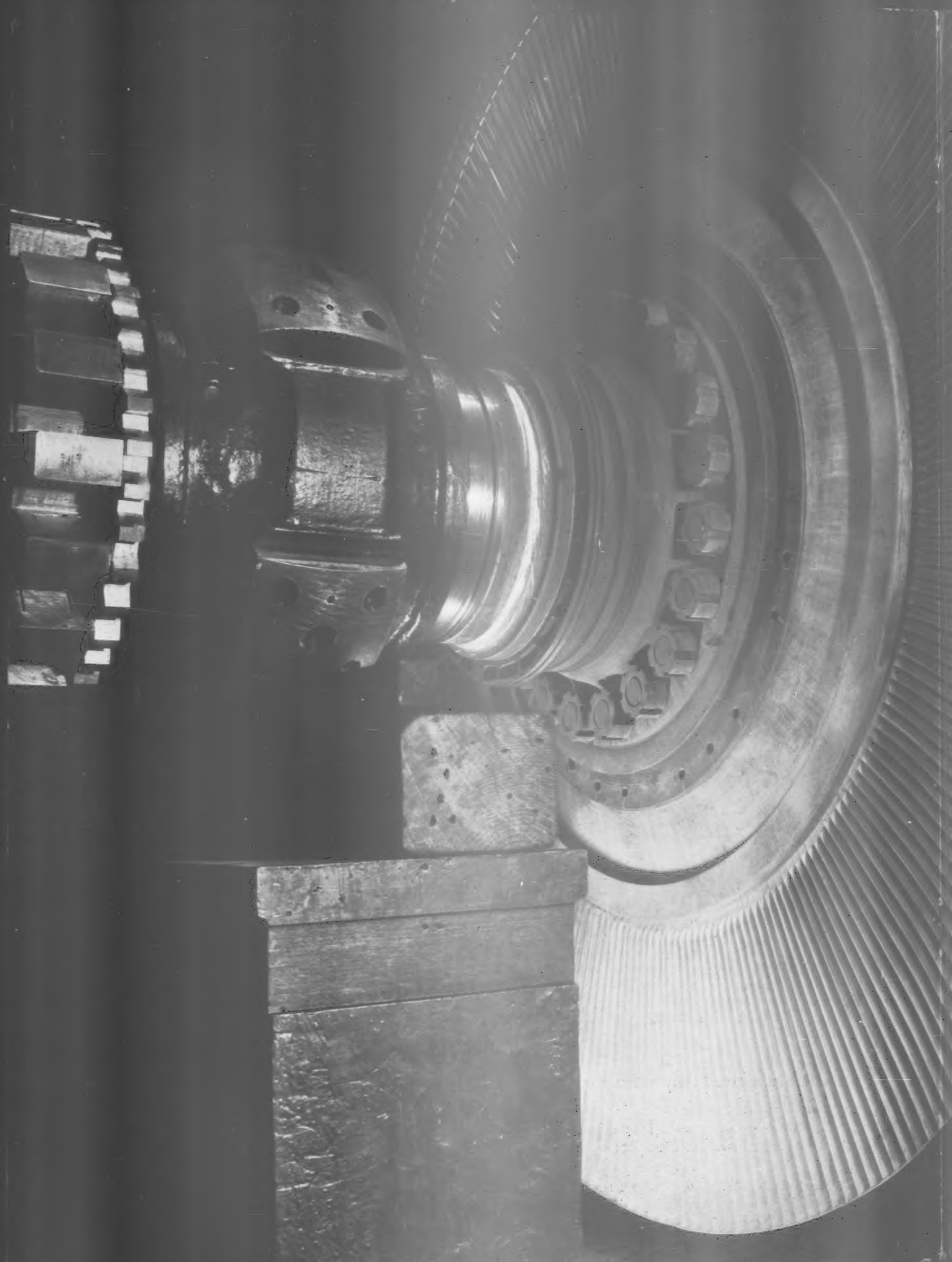


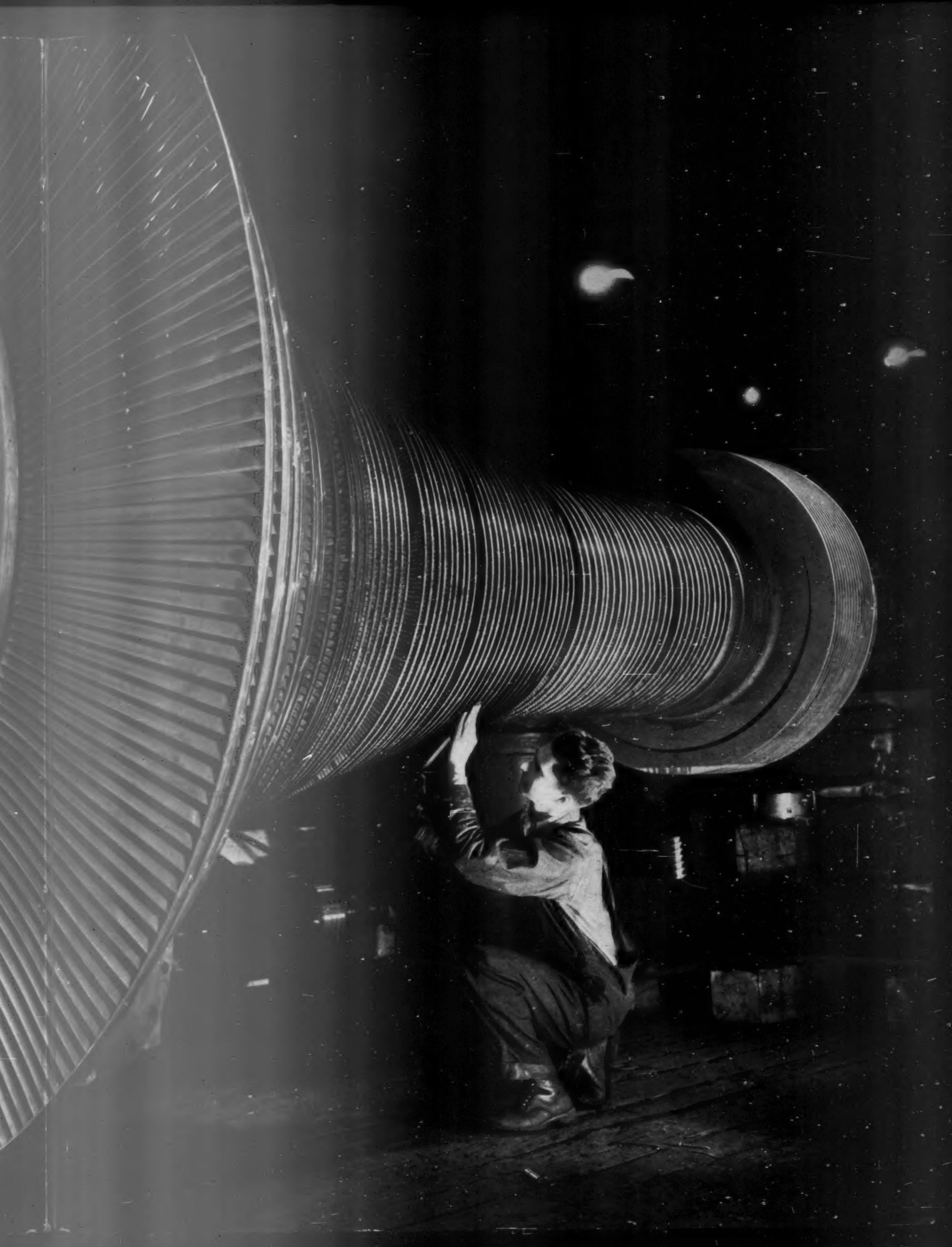
Impulse unit of 450 hp, 300 kw, 1200 rpm, 1250 ft head. The flow of water is directly controlled by the governor.

rendered by the unit, as well as the conditions of available water supply head and tailwater elevations, available quantity and quality of water, etc. The time is past when standard stock-in-trade waterwheels can be picked from catalogs, when generators can be purchased in advance as bargains and the turbine merely hitched up to them. Also properly belonging to the past is the practice of forcing turbine manufacturers to adhere to specifications arbitrarily drawn up without previous consultation of turbine experts capable of analyzing the underlying conditions of a water power site and of the service to be rendered by the hydro-electric unit.

Today most of the important hydro-electric developments are carefully analyzed and specifications calling for bids of the generating equipment are discussed with leading manufacturers before final specifications are issued. It is this practice which has contributed to the gratifying fact that hydro-electric developments in the United States have become recognized abroad as examples worthy of duplication under suitable conditions.

ON NEXT PAGE: Photograph of the rotor of a 30,000 kw 1500 rpm reaction type steam turbine receiving finishing touches in shop before being shipped to a large public utility.





ENGINEERING FUNDAMENTALS

STARTING SYNCHRONOUS MOTORS

● When the a-c winding of a polyphase synchronous motor at standstill is connected to an a-c voltage source, the instantaneous resulting current is determined entirely by the impedance of the windings. The value of this impedance therefore determines the current inrush in starting, which in general is 250 per cent to 600 per cent of the motor full load current with full voltage applied. This initial current is unaffected by the value of connected load and has a low lagging power factor, 20 per cent to 30 per cent.

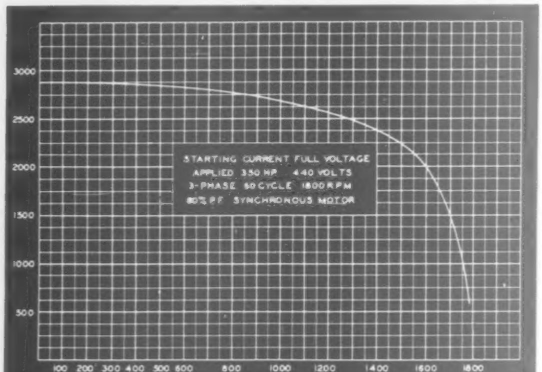


Fig. 1

Figure 1 shows the starting current between standstill and full speed for an 1800 rpm synchronous motor. The initial inrush on full voltage is approximately 600 per cent. Generally the inrush is higher on higher speed motors.

The initial starting kva is proportional to the square of the applied voltage because (neglecting saturation) the impedance is constant. Therefore the current flowing is directly proportional to applied voltage, and consequently at half normal voltage the current flowing is one-half that which would flow if full voltage were applied. The resultant kva then is one-quarter of the starting kva at normal voltage. Similarly, with one-quarter voltage applied, the resultant kva would be one-sixteenth of the starting kva at normal voltage.

Thus, where it is necessary to reduce the initial starting current in order to minimize disturbance on the power system, a reduced voltage is applied at the start, and after partial acceleration full voltage is applied. Usually this is accomplished by either an auto-transformer or a reactor.

The most efficient of these, from the standpoint of current drawn from the line, is the auto-transformer because the total kva drawn from the line (neglecting magnetizing current and transformer losses) is applied directly to the motor terminals; whereas, with the reactor, assuming 50 per cent voltage applied to the motor, 50 per cent of the kva drawn from the line is consumed as voltage drop in the reactor. This kva consumed in the reactor, due to the high inductance of the reactor, is of very low power factor. It is, therefore, in the nature of a voltage drop and not a power loss, the only power loss being the actual I^2R loss in the reactor, which is in the order of five per cent of the kva rating of the reactor.

The synchronous motor as such has no starting torque since it depends for its torque on the attraction between rotating magnetic poles of the a-c winding and the poles of opposite polarity excited from direct current in the field winding, and so must be started without excitation on the field winding. Motors of this type then have a squirrel cage winding imbedded in the pole pieces so that they may be started as induction motors.

From Fig. 1 it is seen that the starting current does not decrease appreciably until about 90 per cent speed is reached, and likewise the power factor of this current remains low during this time. Above this speed the current drops sharply, and the average power factor increases accordingly.

It follows that the duration of this high current is dependent on the load being accelerated.

Between zero speed and actual synchronism, there is relative motion between the field poles and the armature magnetic poles, i. e., the field windings cut flux lines produced by the armature winding. An alternating voltage is therefore induced in the field winding. The ratio of the number of turns in the field winding to the number of turns in the armature is quite high, and so a relatively high voltage is induced in the field, which may become high enough to endanger field insulation if the field winding is left open during starting. For this reason, the field winding is generally short-circuited through a suitable resistance during starting. The value of this "combination starting and discharge" resistance affects the magnitude of the starting torque, because it controls the power factor of the current induced in the field windings.

When the motor has accelerated as far as it will in starting, field is applied to cause it to "pull into step." It is generally agreed that a synchronous motor must be able to accelerate its load to 95 per cent speed in order to pull into step when field is applied. Practically all present-day synchronous motor starters apply field automatically.

INVENTIONS FOR SALE

• Harold S. Silver
PATENT ATTORNEY . . . ALLIS-CHALMERS MANUFACTURING CO.

If Necessity be the mother of invention, certainly Commercial Production is the food on which the infant grows lusty and strong. The problem of feeding the infant is often a grievous one.

Few inventors, other than employees of manufacturing companies, have the facilities at hand for commercially producing their brain children. Perhaps a market must be created. Perhaps a large selling corps is necessary to persuade the buying public that the new device is a real improvement over existing structure. Perhaps the invention is an improvement in a highly specialized line of manufacture. Probably the inventor has no ready cash with which to gamble; or, although certain that his baby, if properly nurtured, will revolutionize the industry, would rather gamble with someone else's money.

The inventor must, therefore, either find a provident speculator who will finance the inventor in commercial production of the invention, or find some manufacturer who will take over and commercially produce the invention on a royalty basis or outright sale. If neither can be found, the inventor has little choice left except to turn the invention over to a patent promoter for possible but improbable disposal.

• Safeguard against loss of rights

Before any of the above steps are taken, the inventor should guard against loss of his rights in his invention by obtaining the best evidence possible as to dates, origin, and subject matter of his invention. He should, if possible, perfect his rights by patenting the invention or at least by filing a patent application. If neither is feasible, he should complete his invention by reduction to practice, that is, by embodying it in a successfully operated full size device, and he should have evidence thereof. If no reduction to practice has been made, evidence of conception of the invention in the form of signed, dated, and witnessed sketches and description should be obtained.

• The manufacturer's considerations

The inventor usually submits his invention to some company manufacturing the line of goods to which his invention pertains. Let us consider the plight of the manufacturer when an inventor comes in with:

1. an embryo idea;
2. an invention actually reduced to practice and disclosed to others;
3. an invention on which a patent application has been filed;
4. a patented or otherwise published invention.

The manufacturer must consider the matter from at least three angles:

(a) commercial value;

(b) possible trusteeship after disclosure;

(c) extent and effect of confidential relation under which invention is disclosed.

From the commercial value standpoint any invention is more or less "a pig in a bag." The value of a patented invention is, of course, more definite after litigation of the patent in a court of last resort. A recently issued patent may, moreover, within two years from date of issue, become involved in an interference proceeding and the claims thereof taken by another. Inventions for which patent applications have been filed may become involved in an interference or may never mature into a patent because of prior art or statutory bars. Inventions which have been actually reduced to practice (embodied in a successfully operated full size device) at least have had a demonstration as to operativeness and utility.

Mere ideas (unpatented paper inventions), not reduced to practice, are pregnant with possibilities of commercial failure. Failure may be due to the fact that patent protection is not obtainable. It may be due to undesirable engineering features, which will appear only when an attempt is made to embody the invention in a commercial device. In general, therefore, patented inventions have an initial commercial value greater than unpatented inventions.

If a manufacturer draws an arbitrary line and will consider only patented inventions, he pursues the safe middle way, avoiding the possible greater heights of success and lower depths of failure of unpatented inventions. A manufacturer, by providing laboratory facilities for experimentation and

trial of an invention prior to patenting, may open broader views thereof or side-lights thereon having more commercial importance than the main invention. By providing competent patent counsel, skilled especially in the art to which the invention pertains, a manufacturer may obtain a patent of a commercial value considerably greater than a patent for the same invention procured by patent counsel unfamiliar with the particular art or commercial situation.

Refusal of a manufacturer to consider unpatented inventions may have undesirable repercussions from the sales policy and internal harmony standpoints. Improvements are sometimes made by customers or potential customers who often submit their invention to the manufacturer. Such submission may be made through the contact men of the manufacturer, that is, the salesmen or engineers. An arbitrary refusal by the manufacturer to consider any and all unpatented inventions creates no good will between administrative and sales departments or between company and customer.

A manufacturer must consider the possible trusteeship which he has in inventions submitted to him. If a manufacturer agrees to obtain patent protection for an invention and then negligently handles the prosecution of the application to the detriment of the inventor's rights, the inventor might be entitled to recover damages suffered through the breach of trust. It is believed any such breach would be provable only if flagrant; that ordinary diligence on the part of the manufacturer would be sufficient under the trusteeship.

• Confidential relationship

A confidential relationship arises between a manufacturer and an inventor submitting an invention. The manufacturer owes the inventor a duty not to disclose the invention generally to others. In equity, if an owner of real property stands silent while another "sells" such property to a third person, the owner is estopped from later claiming the property as against such third person. If an inventor submits an invention to a manufacturer for consideration and the manufacturer has a similar anticipating invention, and the manufacturer stands silent as to his own invention, he may be estopped from later asserting that his invention was prior. This is especially true if patents on the manufacturer's invention would dominate the inventor's invention.

It is believed that the "confidential relationship" under which an inventor discloses an invention to a corporation by disclosing it to an employee thereof would not prohibit such employee from disclosing the invention to the corporation patent counsel and engineers for examination as to its merits from patent and engineering standpoints. Further, arrangement should be made so that patent counsel would not be prohibited from disclosing the invention to associates or confidential agents for the purpose of examination as to its patent merits.

• Discovery of prior art

Under ordinary conditions, the right of a manufacturer to use prior art devices should not be prejudiced by a disclosure to him of an invention. But take, for example, the case where a manufacturer may make rubber dishes for a molded dessert. An inventor submits in good faith as his invention the forming in the rubber of the reverse of the company monogram so that it would appear correctly on the dessert. The manufacturer had not thought of the idea but upon search finds reversed monograms in molding receptacles generally to be old. Is he equitably entitled to use the idea on his dessert dishes without compensation to the one who directed his attention thereto?

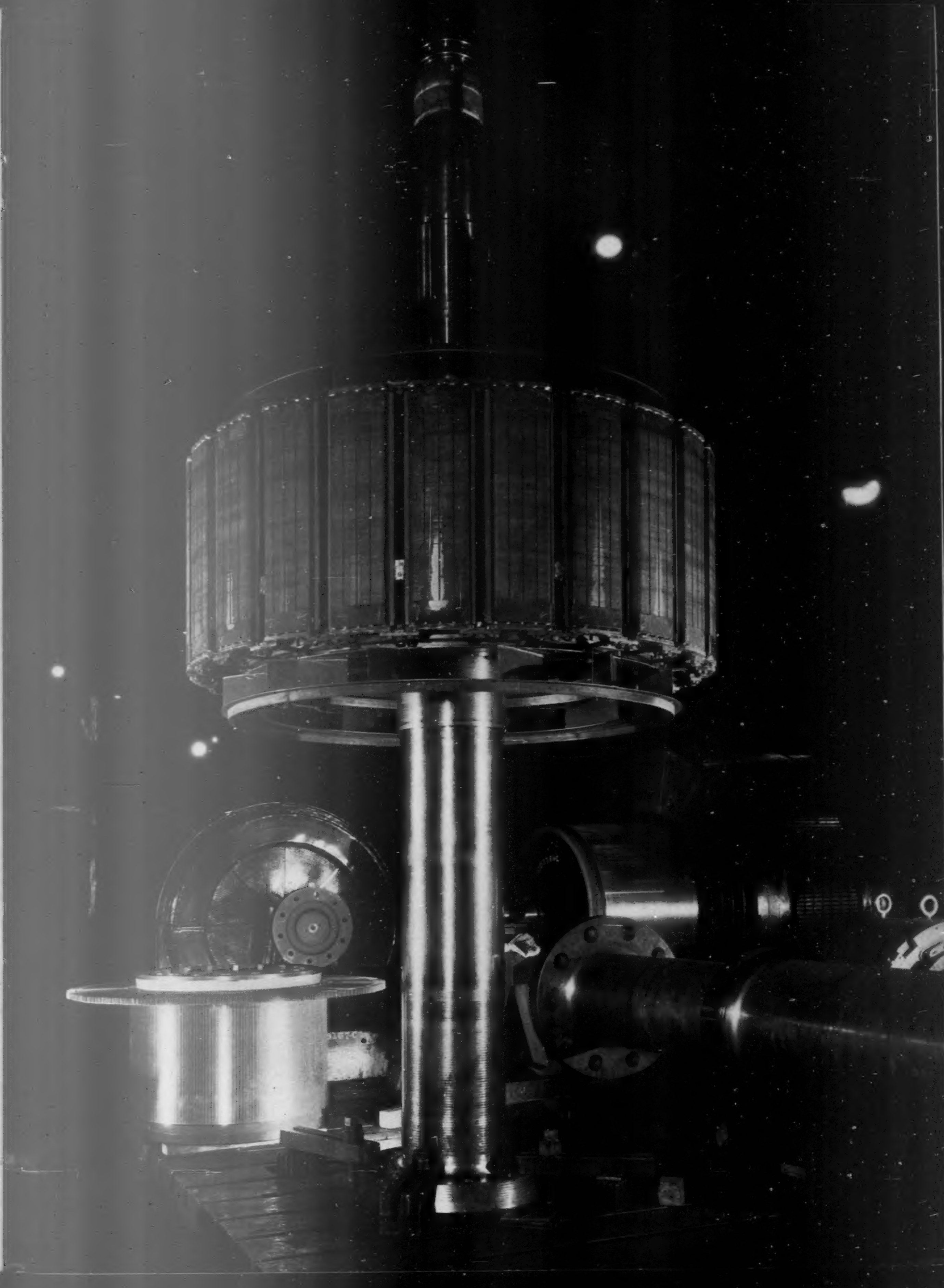
• To minimize misunderstandings

Misunderstandings between inventor and manufacturer to whom an invention is submitted could be minimized by the following precautions:

1. Inventors should, if possible, protect their rights prior to submitting an invention by
   (a) actual reduction to practice (successfully operated full size embodiment);
   (b) constructive reduction to practice (filing a patent application);
   or if unable to do either (a) or (b) by
   (c) obtaining proof of disclosure to others, (signed, dated, and witnessed sketches and written description).
2. Agreement before disclosure regarding the manufacturer's right to disclose for search purposes and regarding manufacturer's right to use prior art fully teaching the invention.
3. If there is a conflict with the inventions of the manufacturer, the matter of further consideration should be deferred until the inventor has his patent.
4. An equitable policy of compensation for "suggestions" such as the dessert mold type above, where but for the suggestion, the manufacturer would have remained uninformed of the "new" idea.

It is believed the above would increase the invention birth rate and the nourishment available in the form of commercial production. Infant inventions would become more healthy and have a better chance of living to useful maturity.

AT RIGHT: The rotor of one of three 4300 hp vertical synchronous motors to be used for driving centrifugal pumps in the Iron Mountain Station of the Colorado River Aqueduct.



REVERSING MOTORS FOR HIGH-SPEED PLANER DRIVES

• G. E. Reiff
ELECTRICAL DEPARTMENT . . . ALLIS-CHALMERS MANUFACTURING CO.

● The demand for increased production in the machine shops, the advent of cutting steels to withstand higher cutting speeds, and the desire to obtain maximum output from machine tools have led to pronounced improvement in the development of electrical drives for fabricating metals, both cast and rolled, used in the various types of machinery. This development has been particularly notable in machine tools such as planers and slotters, where the need of improvement is more urgent because the first cost or investment in these tools is high and the production or output is low in comparison with other types of machine tools.

The planer builder was until recent years very much handicapped in obtaining the maximum output that planers were capable of delivering, because of the difficulty of obtaining motor drives which would satisfactorily absorb and dissipate the energy stored in the revolving and reciprocating parts of the planer and its drive at the moment of reversal.

• A-C motor inflexible

The most satisfactory drive for planers of medium and large size is a reversing motor geared directly to the planer drive. Such motors are, with very few exceptions, direct current, compound wound, having interpoles. The question is often asked if an alternating current motor can be used for reversing planers. A few drives utilizing a-c induction type motors have been built using two or more stator windings or having the stator windings so arranged that the number of poles can be changed at will. Resistance is also placed in the rotor or secondary circuit through slip rings to limit the magnitude of current on reversal. On a 60 cycle circuit such a motor would have a synchronous speed of 1200 rpm with six poles, 400 rpm with 18 poles, and 300 rpm with 24 poles. The two lower speeds might be used for cutting stroke and the higher speed for return. At the time of reversal a series of resistances are inserted in the rotor circuit, and these are successively cut out by a series of relay coils as the current decreases with the increasing speed after the reversal.

The alternating-current motor is more expensive and of lower efficiency than the direct-current motor, and at the most will give only two cutting speeds. The control is also more expensive and much more complicated than the direct current drive. The a-c motor for this service is very inflexible, and to make it flexible for two cutting speeds means that the rotor is necessarily larger and heavier, with a greater WR^2 or moment of inertia. Such characteristics as these mean greater power consumption for reversal, lower efficiency, slower reversal and acceleration.

• Two types of d-c motors used for reversing planer drives

Because of its superior electrical and mechanical characteristics, the direct-current, adjustable speed motor, is used for practically all reversing planer drives. These motors, depending upon the production required of the planer, are divided into two types: constant voltage motors, which operate with constant voltage on the armature, in which the speed is varied by varying the field strength, changing the shunt field current; and variable voltage motors, in which the speed is varied by changing the shunt field current for higher speeds and varying the impressed voltage on the motor armature for lower speeds. The latter type permits a much wider range in speed and can be set for the correct speeds to remove the maximum amount of metal per unit of time.

Until recent years practically all planer motors were of the constant voltage class, but high-pressure production and the advent of super planers have necessitated the development of variable voltage drives in order to utilize to a fuller extent the improvements made by planer builders. This led to the development and perfection of the variable voltage drive for high speed planers.

One such high speed planer drive, described in this article, consists essentially of a planer motor, a motor-generator set, including a small exciter (unless direct current is available), and a control panel. A typical planer motor is shown in Fig. 1.

Fig. 1

It will be noted that the motor has a comparatively small diameter and is longer than the standard, general purpose motor. This ratio of diameter to length is used to keep the flywheel effect, or WR^2, as low as possible in order to minimize the power consumption on reversals and acceleration and to obtain reversals and acceleration in minimum time. The motor has hinged solid covers over the upper half of the commutator housing to insure protection against falling chips, etc., and at the same time permit quick inspection and easy access to the brushes and commutator. The two lower openings of the housing, together with the grid construction of the rear housing, provide ample ventilation for cooling and dissipation of heat.

• Small armature

The importance of keeping the diameter and weight of the armature low is shown by the following example which is part of the calculations used in calculating the time lost and power required because of reversal. It is assumed that the armature has a radius of gyration of .5 ft, the mass of the armature is 700 lb, and mass of all the moving parts at that radius is 800 lb. The circumference of a circle having a radius equal to this radius of gyration is $2\pi \times .5 = 3.14$ ft, which with a ten to one planer gear ratio (a common ratio for planers) means that a pound on the armature moves 31.4 times as fast as a pound on the table. The kinetic energy of a pound on the armature is $31.4^2 = 985$ times as much as a pound on the table. Hence a planer table with its load weighing 30,000 lb would be equivalent to about 31 lb on the armature. From this it is seen that the greater part of the equivalent mass is in the armature, with the gears making up the larger portion of the remainder. Frequently, in order to keep the mass of the armature as small as possible, consistent with good design, materials of lower specific gravity are used in the inactive parts.

• Details

The motor driving the planer is coupled through appropriate gears to the planer table, and the reversals and various cut and return speeds of the table are controlled by regulating the direction of rotation and speed of the motor.

The motor-generator set consists of a suitable generator of ample capacity for driving the planer motor, a direct- or alternating-current motor (depending on the power supply at the installation) for driving the generator, and a small direct-connected exciter for exciting the fields of the planer motor and the generator. The exciter also provides a safety feature in case of power failure and prevents the table of the planer from running off. Figure 2 shows a typical motor-generator set. Since the motor-generator set is not mechanically connected with the planer, it may be located in any convenient place.

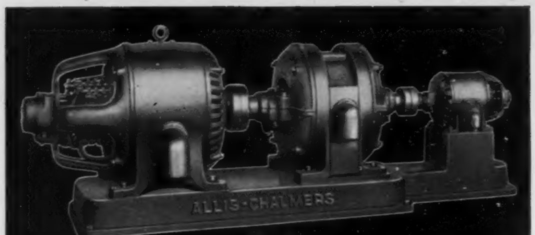


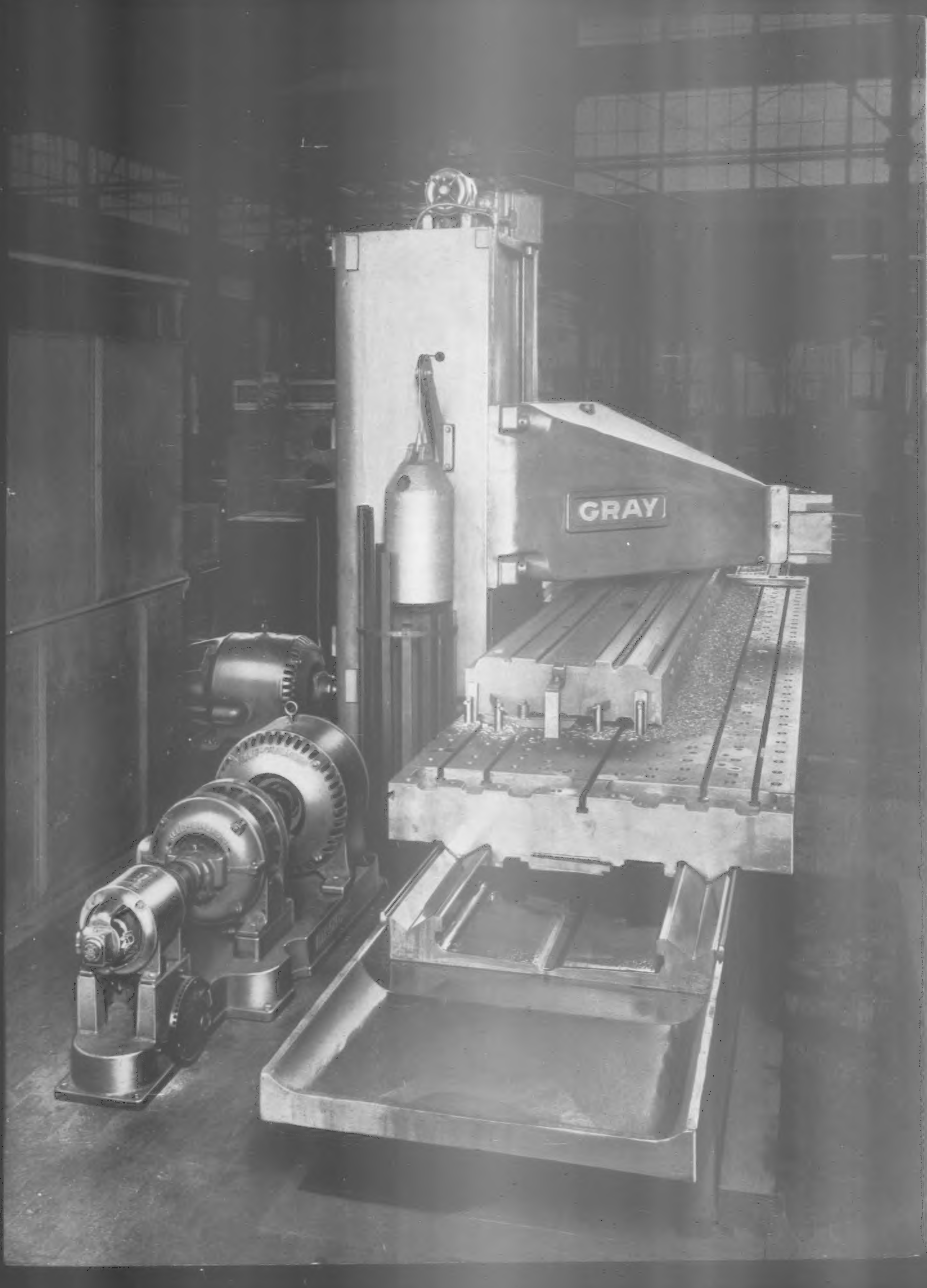
Fig. 2

The control panel contains the necessary switches and speed regulating rheostats, which are all mounted in a steel cabinet that can be placed in any position convenient for the operator. The starter for the motor-generator set is mounted in a steel enclosure separate from that of the planer motor control, and can be mounted near the motor-generator set or the planer, as convenience requires.

Mounted within the planer motor speed regulating panel is the speed regulating resistances for the cut and return strokes, the speed being adjusted by means of hand wheels on the outside of the cabinet. These hand wheels are provided with circular indicating dials which can be used to indicate table speed in feet per minute for both cut and return strokes. A convenient pendent switch is provided for the operator, from which complete control of the planer, except for speed-setting, is obtained. This pendent switch is mounted on a swivel, overhung from the top of the planer, and can be swung to either side of the table as the operator desires.

Three push buttons are ordinarily supplied with this pendent switch, also a stop toggle arm at the lower end which provides quick stopping of the motor by either pulling it or pushing it from the side — very convenient in case of emergency. The other buttons are for start, cut, and return. If desired, other buttons for special functions can be added. The two buttons marked "Cut" and "Return" are for inching and for setting up the work and adjusting the cutting tool. The table moves either forward or reverse only so long as these buttons are held down. As soon as the button is released, dynamic braking is effected and the table stops instantly. In this way very accurate control is obtained over table position. These two upper buttons cause the table to move in the direction indicated regardless of the position of the master switch of the controller on the base of the planer.

The planer motor is direct-connected to the gearing which drives the reciprocating part or table of the planer. The necessary reversal or change of speed is obtained through this motor functioning in response to the control. Current for the motor is supplied by the motor-generator set, and the speed and direction of rotation of the motor are


GRAY

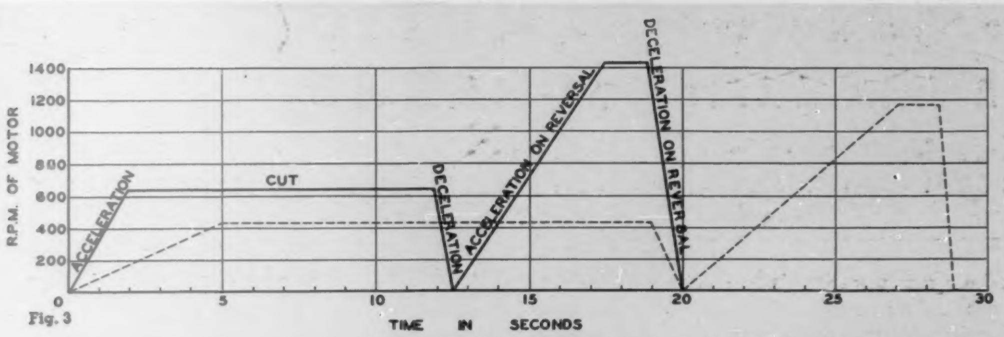


Fig. 3

governed by the voltage and current polarity of the generator.

The voltage of the generator is increased or decreased by increasing or decreasing the field excitation by means of suitable field resistance. As the armature of the reversing planer motor is tied in with the generator armature, its speed will be governed by this voltage with any given field setting of the motor. Reversals are obtained by reducing the voltage to zero, and building it up again in the opposite direction by reversing the polarity of the generator excitation. By reversing in this manner, only very small currents are made and broken, and very little energy is dissipated, whereas in the ordinary reversing planer motor drive, using constant voltage, heavy current circuits are broken, resulting in considerable wear and tear on the control equipment.

• Speeds

The different cutting and return speeds are obtained by adjusting the hand wheel which controls the cutting and return speed field resistances. These resistances are independent of each other, and either the cutting or return speed can be changed without changing the other. With this arrangement, the most efficient return speed can be obtained, depending upon the length of the cut and speed of the cutting stroke.

Through the use of variable voltage, a wide range of cutting speed, as well as a wide range of return speed, can be obtained. In addition to the speeds obtained through varying the voltage, which are the speeds below the full field speed, higher speeds above the full voltage speed are afforded by using field resistance in the reversing motor. With this combination a wide speed range from the lowest cutting speed to the high return speed can be obtained. This range is very seldom less than eight to one and in actual practice 25 and 30 to one have been obtained.

Another valuable attribute of this type of high-speed planer drive is that it makes it possible to speed up the tool between cuts during a cutting stroke, where the work has an air gap between cuts, as in connecting rods. It also makes it possible to speed up the cut after the tool has entered the work, as is sometimes desirable in rail and frog and switch work. As illustrated diagrammatically in Fig. 4, this is accomplished by small suitable switches mounted on the planer bed, and actuated by movable dogs on the planer table, which actuate the motor field resistances.

AT LEFT: Electrically driven high speed planer showing variable voltage equipment consisting of motor-generator set with exciter, and planer motor shown in background at left.

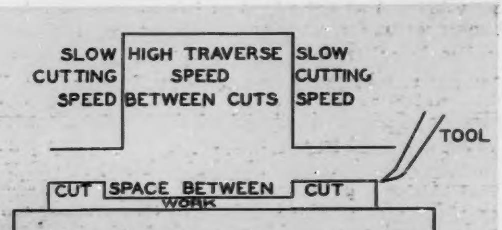
Figure 3 shows a typical cycle of a high-speed planer drive from test, showing a saving in time and increase of production over an older type of drive of 31 per cent. This test was made on a 60" x 60" x 15' double housing planer, machining a five-ton casting 12 ft long.

• Advantages

Summarizing the advantages of this type of high-speed planer drive, the following may be listed:

I. General
   a. Low power consumption in reversing and accelerating.
   b. Good speed regulation.
   c. Good commutating qualities, resulting in low maintenance.
   d. Smooth reversals without shock or undue strain on planer and gears due to the magnetic cushioning.

II. Control
   a. Plugging for reversing, which gives quickest reversals.
   b. Dynamic braking stop in cast of voltage failure.
   c Dynamic stop on failure to reverse properly.



SHOWING USE OF ACCELERATING SWITCH FOR SPEEDING UP BETWEEN CUTS SOME DISTANCE APART

Fig. 4

ELECTROMAGNETIC VIBRATING SCREENS

• C. S. Lincoln
CRUSHING AND CEMENT DIVISION . . . ALLIS-CHALMERS MANUFACTURING CO.

● Mechanically actuated vibrating screens have been used for fine screening for a great many years. One such use is well known in the flour milling field where very fine separation is obtained through the use of vibrated special silk screen cloth. This is obviously unsatisfactory for materials of abrasive nature such as minerals and ores, which require metallic screen cloth. As a result many mechanical devices for fine screening of abrasive materials have been tried with varying degrees of success. The most recent development in the art of fine screening of abrasive materials is the electromagnetically vibrated screen. This has been found to be quite satisfactory because it makes it possible to obtain comparatively sharp, rapid vibrations with a minimum of wear and at a relatively slight expenditure of power.

• Operation of older types

One of the earliest electromagnetic screens consisted of a rectangular stationary frame in which was fastened an auxiliary frame which carried the wire screen cloth. An electromagnet and a stop member or anvil were carried by the stationary frame over the screen cloth. In operation the armature, which was attached directly to the screen cloth, was attracted by the magnet until it struck the stop member or anvil, thus bringing the armature to a sudden stop. Since the armature was attached directly to the screen cloth the latter partook of the movement of the armature, being repeatedly raised and suddenly stopped. This action tended to dislodge any particles which adhered to the cloth, thereby preventing clogging of the screen. Since the armature was connected to the screen near the center of the screen, this movement of the armature resulted in a maximum vibration near the middle of the screen, tapering down to practically no vibration at the edges of the screen. Moreover, the construction was noisy, due to the hammering of the armature on the stop member, and resulted in rapid wear. The operation of this screen was later improved by placing the electromagnets at the corners of the auxiliary screen frame, the armatures being attached to the corners of the screen frame. In this way the entire screen with auxiliary frame was vibrated as a unit. As in the prior construction, the pull of the magnets in this screen was in one direction only, the return movement being effected by springs. The intensity of the vibrator was regulated by changing the voltage, and some type of intermittent make and break device was required to energize electromagnet intermittently.

Another type of electromagnetic screen, instead of using a make and brake device, superimposes a direct current on the energizing alternating current supplied to the coils, so that one side of the sine wave of the alternating current is partially canceled and the other side amplified to produce intermittent attractive force on the armatures. This also relies on spring action to produce the return movement of the screen.

• New development overcomes power waste

In the more recent development of electromagnetically vibrated screens, the vibration is effected by upper and lower magnets between which the armatures are located. A flexible reed or bar is fastened at its ends to a substantially stationary frame and near its center carries two separate armatures, one of which cooperates with each of the electromagnets. In this way the movement of the vibrating element in both directions is effected by means of electromagnets so that no power is wasted in overcoming spring pull, as was the case in previous devices. Moreover, each electromagnet operates on a separate armature, and this construction obviates reversal of flux in the armature with its attendant power losses. The screen body is carried by supporting rods carried by the two flexible reeds of the type described above.

The electromagnets are energized by any source of single phase alternating current. Obviously if the same source of current were used to energize both magnets at the same time, there would be no resultant movement since the electromagnets would oppose each other. The upper and lower magnets are therefore energized alternately by means of a bank of copper oxide rectifiers.

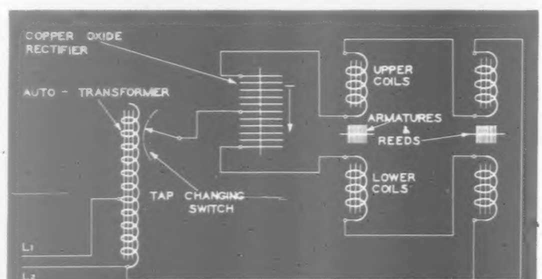


Fig. 1

• Application of alternating current

Figure 1 shows the system used in applying alternating current to this type of electromagnetic vibrating screen. A variable auto-transformer is used so that the voltage impressed on the magnet coils may be varied about 25 per cent on either side of line voltage. In the case illustrated, this voltage regulation is broken up into seven steps, giving three steps below and three steps above, in addition to normal line voltage. It will be noted that one side of the line is brought from the auto-transformer through the tap changing switch to the midpoint of the rectifier bank, and the other side of the line is connected to one end of each set of coils. Thus during one-half of the cycle the current flows through the lower half of the rectifiers, energizes the lower coils, and thence back to line (L_1). During this half of the cycle the upper coils are unenergized, because no appreciable current can flow through the rectifiers in this direction. During the other half of the cycle the upper coils are energized as current passes through them from (L_2) and through the upper half of the rectifier to (L_1). In this manner the upper and lower coils are alternately energized and exert alternate pull on the armatures attached to the vibrating reed, which in turn transmits vibrating motion to the screen body.

Since the flexible bar supports the armatures so that they never come in contact with the electromagnets, there is no hammering action on the screen or armatures. During operation the air gap between each armature and its coil varies from .030 to .040 of an inch.

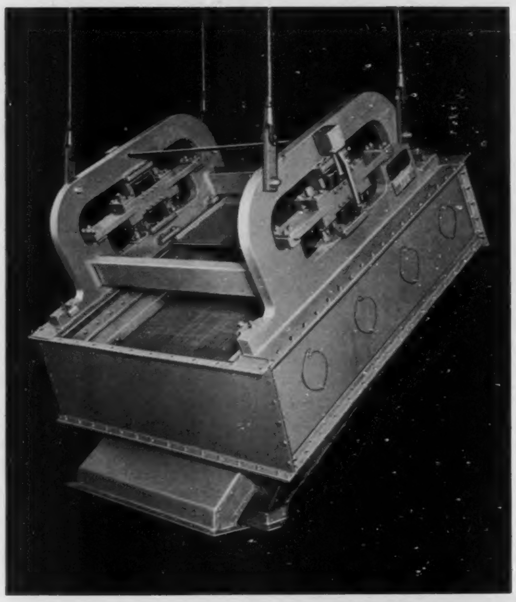
The power required to operate a 4′ x 6′ screen is about 700 watts. Alternating current of any commercial frequency may be successfully used, the frequency of vibration depending upon the frequency of the impressed voltage.

• Capacity

Screens are operated at an angle from 30 degrees to 35 degrees from the horizontal, depending on screening conditions. The capacity of the screen depends upon the nature of the material being treated, the size of the openings in the screen cloth, the slope of the screen, and the frequency of the impressed voltage. Because of the number of factors involved, the capacity of each screening installation has to be calculated individually.

This new type of electromagnetic screen has been in commercial operation for several years, successfully handling heavy tonnages of copper ore and screening at ten mesh (ten screen perforations per linear inch).

Above is shown a shop view of a standard 4′ x 6′ totally enclosed electromagnetic screen of this type for screening at 20 mesh and handling a maximum feed of approximately 20 tons per hour. This screen is of the suspended type, the main frame being carried by four cables attached to the floor above. A part of the top cover plate is removed to show the screen cloth. In this design the enclosure is



Totally enclosed electromagnetic vibrating screen for handling 20 tons per hour, while screening at 20 mesh.

substantially stationary and is rigidly attached to the two heavy side members which carry the electromagnets and in which the vibrating bar is supported. These two heavy side members are connected together at each end with heavy spacers welded to the steel side members. The screen body is attached to the vibrating reeds by suitable supporting rods which pass through holes in the side members and enclosure.

• Construction of parts

It is desirable to have the stationary parts heavy in comparison to the weight of the vibrating screen body, as the relative motion of the parts varies inversely as their relative weight. The screen cloth is tightened by bolts which can be reached through covered holes in the sides, and the screen cloth can be removed and replaced by removing the discharge end plate and top plate. The top plate is quickly removable for inspection of the screen cloth.

The feed openings, as well as the openings in the enclosure for removing the oversize and undersize products from the screen, are flanged and arranged so they can be bolted to suitable spouts, making dust-tight connections. Provision is also made for connection to a dust collecting system.

The auto-transformer and tap changing switch are enclosed in a well ventilated case which can be bolted to the wall near the screen. The rectifiers, consisting of ten units connected in series-parallel, are contained in a well ventilated case which is adapted for mounting on a wall.

It is believed that further development work will still further improve this basic type of screen and lead to wider fields of application.

THE LOADING OF A BANK OF DISSIMILAR TRANSFORMERS

• F. C. De Weese
CAROLINA POWER AND LIGHT CO. . . . RALEIGH, NORTH CAROLINA

● Problems pertaining to the loading of dissimilar transformers can usually be solved readily by the use of symmetrical components, or a modified form thereof. However, this method, when applied to a practical problem, is seldom carried out in sufficient detail to be of much value to the practicing engineer. In the following discussion, intended to be of assistance to that end, a solution of two typical transformer network problems is explained. In the first example discussed, the transformers have identical voltage transformation ratios and unequal impedances; while in the second example the transformers have both unequal voltage transformation ratios and unequal impedances.

Transmission and distribution engineers are interested in knowing how a given load will divide between transformers connected in parallel or in three-phase delta banks. Such information is of great value even when a considerable amount of work is required to obtain it. It is unfortunate that solutions to such problems cannot be made without resorting to more or less involved mathematics; however, to any one possessing a knowledge of vector analysis, the actual solutions are not difficult and very little trouble should be experienced with problems of this nature.

Where dissimilar transformers are connected in a delta-delta bank, two of the transformers usually have similar ratings. The impedances of the three units, however, frequently differ. The procedure for solving the problem under these two conditions follows:

• Case I

This case is based on a transformer network consisting of two 500 kva, and one 333 kva, 13,800 to 2,300 volt transformers connected delta-delta to a balanced three-phase load of 1250 kva, 1000 kw at 80 per cent lagging power factor. The impedances of the transformers are $Z_A = 1 + j5 = 5.10$ per cent; $Z_B = 0.8 + j4 = 4.08$ per cent; and $Z_C = 1.2 + j6 = 6.12$ per cent. In this case it will be seen that the voltage transformation is equal but the impedances differ.

• Case II

In this case the transformers have the same relative kva ratings as in Case I, but instead of the voltage rating of A being 13,800 to 2,300, it is 13,800 to 2,200, from which it will be seen that there are unequal voltage transformation ratios as well as unequal impedances.

The problem is to determine, for both Cases I and II, the division of load between the transformers, the maximum safe load which can be imposed on the bank without exceeding the rating of either transformer in the bank, the secondary output voltage, and the voltage unbalance on the secondary side.

Prior to connecting transformers in delta-delta, the impedance of each transformer in the bank should be known. If this information is not available, the division of load cannot be determined without resorting to an actual test.

Transformer impedances are usually given in per cent; that is, the impedance drop through the transformer windings in per cent of normal voltage at normal load.

In this example it is most convenient to have the impedances expressed in their ohmic values. The conversion from per cent impedance to impedance in ohms can be accomplished by use of the following equation:

$$R + jX \text{ (In ohms)} = \frac{(R + jX)\% \times E^2}{\text{kva} \times 10^5}$$

Substituting the known values of transformer A, for example, and solving for impedance in ohms, the equation reads

$$R_A + jX_A = \frac{(1 + j5)\% \times 2300^2}{1250 \times 100{,}000}$$

$= 0.0423 + j0.2116 = 0.2158$ ohm.

By the same method

$$R_B + jX_B = 0.0338 + j0.1693 = 0.1725 \text{ ohm.}$$
$$R_C + jX_C = 0.0508 + j0.2539 = 0.2590 \text{ ohm.}$$

It is to be noted that the kva value used in the denominator of this equation is that of the load

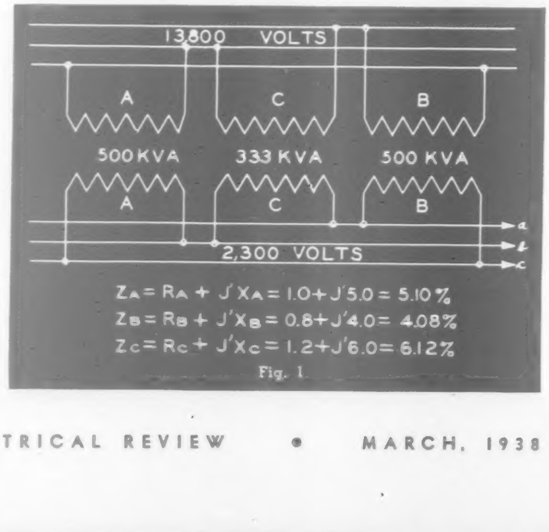


Fig. 1

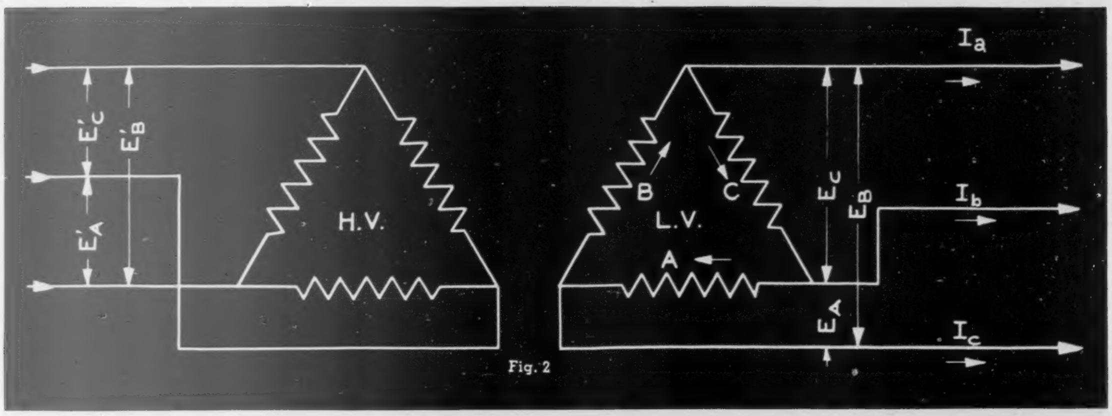


Fig. 2

served by the bank. This value may or may not be the same as the kva rating of the bank, depending on the assumptions made.

The impedance values should be carried out to at least four places, otherwise the final results will not be sufficiently accurate for a check by Kirchhoff's equation to give zero impedance drops.

It is assumed that the primary voltage E'_A, E'_B, and E'_C and the secondary load currents I_a, I_b and I_c are balanced (see Fig. 2). For a load of 1250 kva, at 2300 volts, the absolute value of the current is 313.8 amp.

In order to compute the current flowing in the respective transformer windings, which of course requires vector analysis, it is necessary to know not only the absolute value of the load currents I_a, I_b, and I_c, but also their quadrature components and angular displacement from the vector of reference. E'_A will be taken as the reference vector.

For delta-connected transformers at unity power factor, the line load current is 30 degrees out of phase with the voltage between lines. Accordingly, at 80 per cent power factor, the current will lag the voltage by $30° + 36°52' = 66°52'$. ($36°52'$ is the angle of lag at 80 per cent power factor.) By referring to Fig. 3 it will be evident that I_a will lag E'_B by $6°52'$ and will lead $—E'_A$ by $60° — 6°52' = 53°08'$. The quadrature components of I_a are therefore as follows:

$$1_a\,(—\text{Cos } 53°08' — j \text{ Sin } 53°08')$$
$$= 313.8\,(—0.6 — j0.8) = —188.28 — j251 \text{ vector amp.}$$

Since I_b and I_c are displaced from vector I_a, in a counterclockwise direction, 240 and 120 degrees respectively, their values are $I_b = a^2I_a$, and $I_c = aI_a$. Where $a^2 = —0.5 — j0.866$ and $a = —0.5 + j0.866$ From which

$$I_b = (—0.5 — j0.866)\,(—188.28 — j251) = —123.3 + j288.6 \text{ vector amp.}$$
$$I_c = (—0.5 — j0.866)\,(—188.28 — j251) = 311.5 — j\,37.6 \text{ vector amp.}$$

The value of current flowing in each of the transformer windings can very readily be determined, provided the respective values of I_1 and I_0, which are the positive sequence and zero sequence windings currents respectively, are known.

• Solution for case I:

$$I_1 = \frac{j}{\sqrt{3}} I_a$$
$$= j0.577\,(—188.28 — j251) = 144.94 — j108.7 = 181.17\underline{/—36°52'} \text{ amp.}$$

When the voltage transformations are equal and the impedances differ:

$$I_0 = \frac{—I_1 Z_1}{Z_0} \qquad (2)$$
$$Z_1 = 1/3(Z_A + a^2Z_B + aZ_C)$$
$$= 1/3[(0.0423 + j0.2116) + (—0.5 — j0.866)\,(0.0338 + j0.1693) + (—0.5 + j0.866)\,(0.0508 + j0.2539)$$
$$= —0.02443 + j0.004907$$
$$Z_0 = 1/3(Z_A + Z_B + Z_C)$$
$$= 1/3(0.0423 + j0.2116) + (0.0338 + j0.1693) + (0.0508 + j0.2539) = 0.0423 + j0.2116$$

Substituting in (2) and solving for I_0,

$$I_0 = \frac{(—144.94 + j108.7)\,(—0.02443 + j0.004907)}{0.0423 + j0.2116}$$
$$= \frac{—0.5835 — j0.775}{0.04656}$$
$$= —12.55 — j16.73$$
$$= 20.9\underline{/233°08'} \text{ amp.}$$

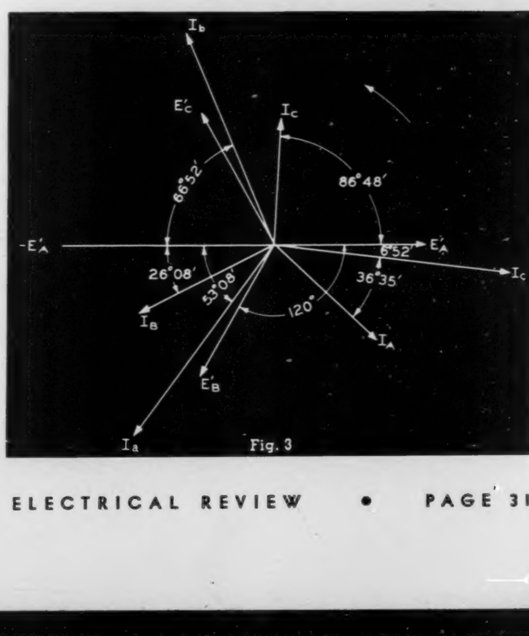


Fig. 3

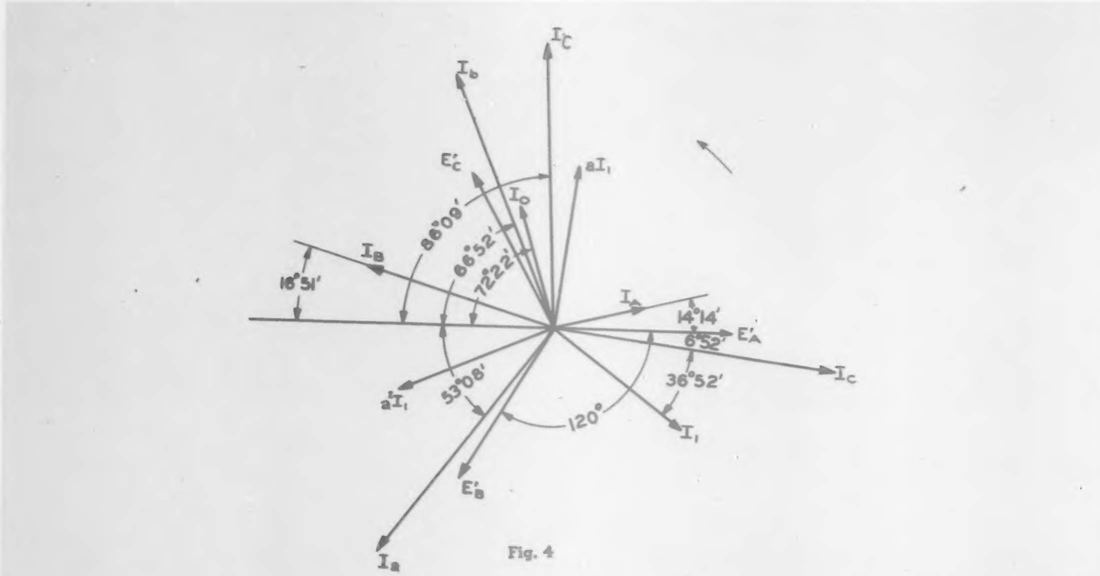


Fig. 4

$I_A = I_0 + I_1$ (3)
$I_B = I_0 + a^2I_1$ (4)
$I_C = I_0 + aI_1$ (5)

From (3),
$I_A = (-12.55 - j16.73) + (144.94 - j108.7)$
$= 132.39 - j125.43 = 182.37\underline{/-43°27'}$ amp.

From (4),
$I_B = (-12.55 - j16.73) + (0.5 - j0.866)$ $(144.94 - j108.7) = -179.15 - j87.9 = 199.55\underline{/206°08'}$ amp.

From (5),
$I_C = (-12.55 - j16.73) + (-0.5 + j0.866)$ $(144.94 - j108.7) = 9.11 + j163.39\underline{/86°48'}$ amp.

$E_A = 2300 - (132.39 - j125.43)$ $(0.0423 + j0.2116)$
$= 2300 - (32.14 + j22.7) = 2267.86 - j22.7$
$= 2268\underline{/-0°35'}$ volts.

$E_B = 2300 (-0.5 - j0.866) - (-179.15 - j87.9)$
$(0.0338 + j0.1693) = (-1150 - j1992)$
$- (8.83 - j33.3) = -1158.83 - j1958.7$
$= 2276\underline{/239°24'}$ volts.

$E_C = 2300 (-0.5 + j0.866) - (9.11 + j163.14)$
$(0.0508 + j0.2539) = (-1150 + j1992)$
$- (-40.96 + j10.6) = -1109.04 + j1981.4$
$= 2271\underline{/119°14'}$ volts.

Check:
$2267.86 - j\ \ 22.7$
$-1158.83 - j1958\ 7$
$-1109.04 + j1981.4$
$-0000.01 + j0000.0$

The maximum voltage unbalance in terms of E_A is equal to $\frac{2276 - 2268}{2268} \times 100 = .352$ per cent.

The load served by each transformer and the total bank load are as follows:

A = 2.268 × 182.37 =	413.6	kva
B = 2.276 × 199.55 =	454.1	kva
C = 2.271 × 163.39 =	371.0	kva
Total	1,238.7	kva

Transformer C under this condition of loading would be loaded to 371/333 × 100 = 111.4 per cent of its kva rating. The approximate maximum load which can be served by the bank without exceeding the kva rating of transformer C is 100/111.4 × 1238.7 = 1111.9 kva.

The value of 1111.9 kva is in error by about 2 per cent. The calculated value for the line currents and voltages is 1091 kva at which load $I_A = 161.4$ amp, $I_B = 173.7$ amp, and $I_C = 144.57$ amp. E_A, E_B, and E_C are 2271, 2279, and 2274 volts respectively.

Under the assumption that the primary voltage remains constant at 13,800 volts, the input to the transformers will be:

A = 13.8 × 182.37 × 0.16667 =	419.5	kva
B = 13.8 × 199.55 × 0.16667 =	459.0	kva
C = 13.8 × 163.39 × 0.16667 =	375.8	kva
Total	1,254.3	kva

It is immaterial whether the input or output value is used to determine the safe load which can be imposed on the bank.

• Solution for case II:

Let N_A, N_B, and N_C be the ratio of the secondary to the primary voltage of the respective transformers. $N_A = 2200/13800 = 0.15942$. $N_B = N_C = 2300/13800 = 0.16667$.

When both the voltage transformers and impedances are unequal, as in this case,

$$I_0 = \frac{E'_A N_1 - I_1 Z_1}{Z_0} \qquad (6)$$

$N_1 = 1/3\ (N_A + a^2N_B + aN_C)$
$= 1/3\ [0.15942 + (-0.5 - j0.866)\ 0.16667$
$+ (-0.5 + j0.866)\ 0.16667] = -0.002415 + j0$

Z_1, as computed in Case I, is $-0.02443 + j0.004907$
Z_0, as before is $0.0423 + j0.2116$
Substituting in (6), and solving for I_0,

$$I_0 = \frac{13800\,(-0.002415 + j0)}{0.0423 + j0.2116} - \frac{(144.94 - j108.7)\,(-0.12443 + j0.004907)}{0.0423 + j0.2116}$$

$$= \frac{(-33.327 + j0) - (-2.992 + j3.3556)}{0.0423 + j0.2116}$$

$$= \frac{-1.992 + j6.277}{0.04656}$$

$$= -42.8 + j134.6 = 141.24\angle 107^\circ 38' \text{ amp.}$$

From (3),

$$I_A = (-42.8 + j134.6) + (144.94 - j108.7)$$
$$= 102.14 + j25.9 = 105.37\angle 14^\circ 14' \text{ amp.}$$

From (4),

$$I_B = (-42.8 + j134.6) + (-0.5 - j0.866)(144.94 - j108.7)$$
$$= (-42.8 + j134.6) + (-166.6 - j71.17)$$
$$= -209.4 + j63.43 = 218.8\angle 164^\circ 05' \text{ amp.}$$

From (5),

$$I = (-42.8 + j134.6) + (-0.5 + j0.866)(144.94 - j108.7)$$
$$= (-42.8 + j134.6) + (21.66 + j179.87)$$
$$= -21.14 + j314.47 = 315.18\angle 93^\circ 51' \text{ amp.}$$

$$E_A = 2200 - (102.14 + j25.9)\,(0.0423 + j0.2116)$$
$$= 2200 - (-1.2 + j22.7) = 2201.2 - j22.7$$
$$= 2203\angle -0^\circ 36' \text{ volts.}$$

$$E_B = 2300\,(-0.5 - j0.866) - (-209.4 + j63.43)(0.0338 + j0.1693)$$
$$= (-1150 - j1992) - (-17.86 - j33.3)$$
$$= -1132.14 - j1958.7 = 2262\angle 240^\circ 00' \text{ volts.}$$

$$E_C = 2300\,(-0.5 + j0.866) - (-21.14 + j314.47)(0.0508 + j0.2539)$$
$$= (-1150 + j1992) - (-80.96 + j10.62)$$
$$= -1069.04 + j1981.38 = 2251\angle 118^\circ 21' \text{ volts.}$$

Check:

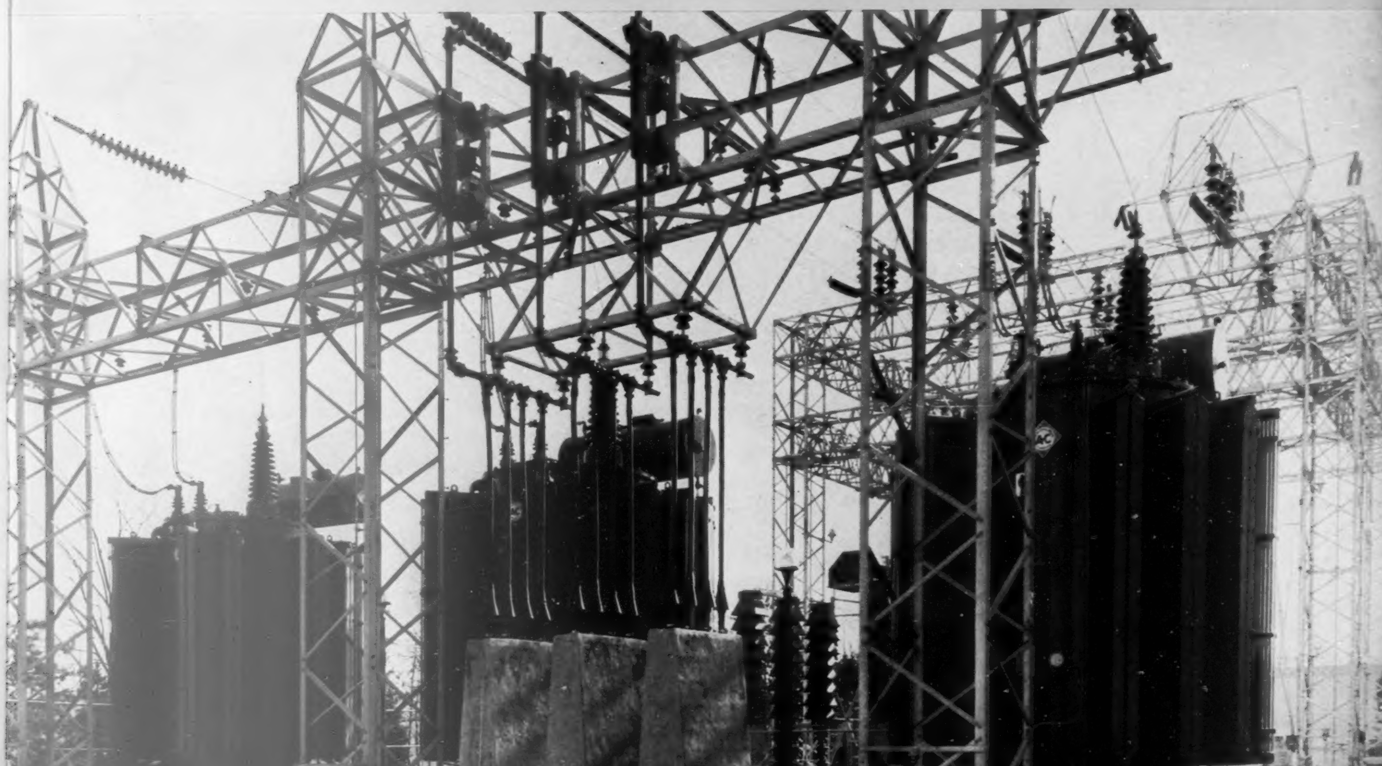
$$\begin{array}{r} 2201.20 - j\;\;22.70 \\ -1132.14 - j1958.70 \\ -1069.04 + j1981.38 \\ \hline 0000.02 - j0000.02 \end{array}$$

The voltage unbalance in terms of E_A is equal to $\frac{2262 - 2202}{2202} \times 100 = 2.72$ per cent.

The distribution of load throughout the transformer network and the total load served by the bank are as follows:

A =	2.202 × 105.37 =	232.0 kva
B =	2.262 × 218.80 =	494.9 kva
C =	2.251 × 315.18 =	709.5 kva
Total		1,436.4 kva

Transformer C is loaded to $709.5/333 \times 100 =$ 213 per cent of its rating.



Bank of three 20,000 kva transformers hv 138,000 volts lv 13,200 volts.

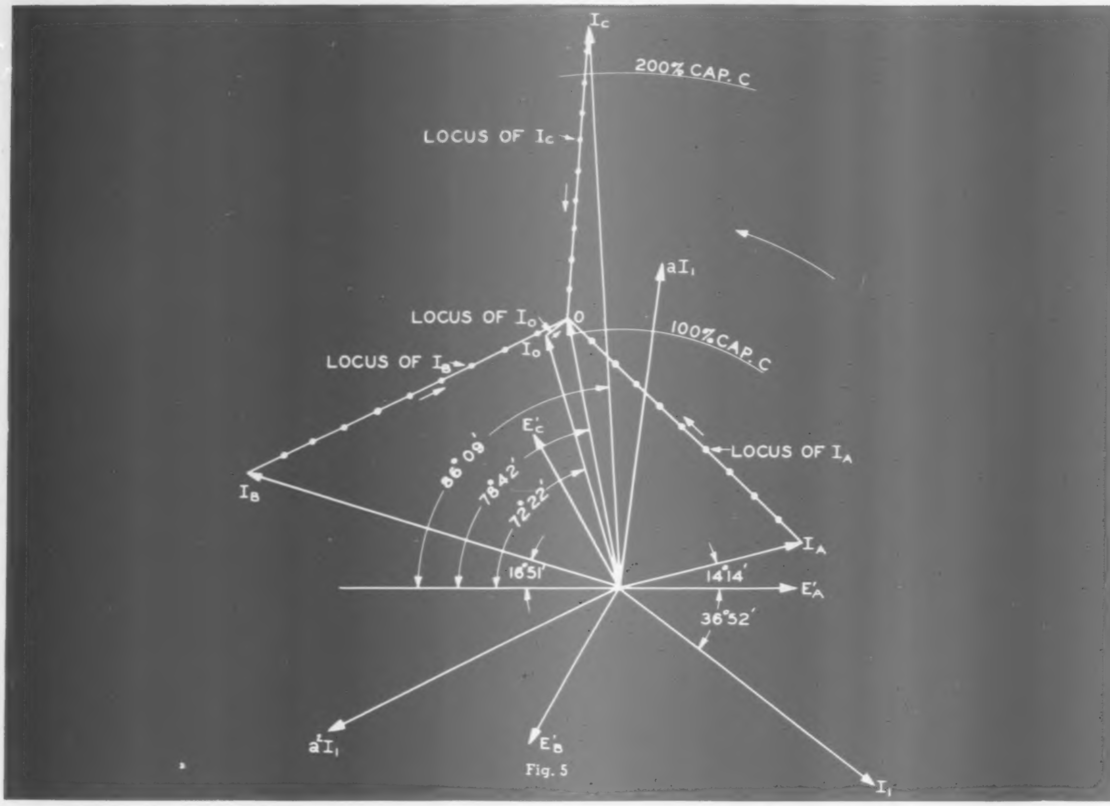


Fig. 5

The value of I_0 at the assumed load of 1250 kva has been computed to be $-42.8 + j134.6$. It will be evident from a study of Equation 6, that as the load is reduced, due to the reduction of I_1, I_0 will increase in value. With all the load removed, I_1 will of course disappear and (6) will reduce to

$$I_0 = \frac{E'_A N_1}{Z_0} = \frac{13{,}800\,(-0.002415 + j0)}{0.0423 + j0.2116}$$
$$= -30.25 + j151.33 = 154.4\underline{/118°00'}\text{ amp.}$$

Since the full load current rating of transformer C is 144.33 amp, this value will fall on the 100 per cent capacity line in Fig. 5. It is clear then that I_0 at no load is slightly in excess of the rating of C, and there can be no useful load safely imposed on the bank. This is a rather unusual diagram and shows quite clearly just what happens as the load is reduced. I_0 not only increases in value with reduced load but changes in phase, shifting from point I_0 to point 0, at which time the useful load has all been removed and the winding current loci converge.

From the above derived results it is clear that no attempt should be made to operate transformers with unequal voltage transformations in a delta bank without first determining what will happen, as the bank may be entirely inoperative.

I_0, which is nothing more than the circulating current in the delta due to the difference in impedance and voltage ratio, at a load of 1250 kva is $141.24/144.33 \times 100 = 98.2$ per cent of the normal rating of transformer C.

At no load it is $154.42/144.33 \times 100 = 107$ per cent. From this it will be seen that the bank cannot supply a useful load.

Calculations have been made to show the value and phase position of I_1, I_A, I_B and I_C at intervals of ten per cent from an assumed load of 1250 kva to zero load. From these values and phase positions the current loci have been plotted in Fig. 5. Checks made for several of the calculated values show that Kirchhoff's law has been satisfied in each case.

The above calculations indicate that vector analysis is a useful tool for the solution of problems involving the loading of dissimilar transformers. It is a tool which merits wider use than it receives at present.

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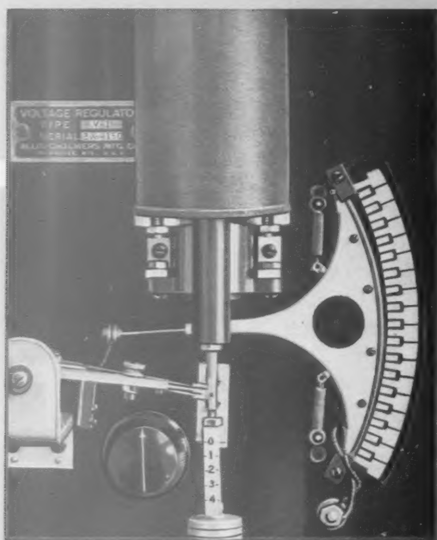

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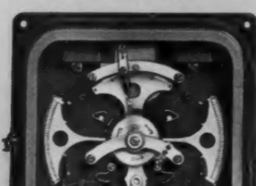

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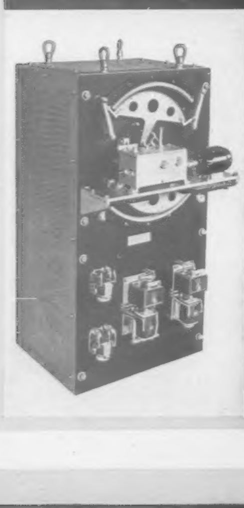

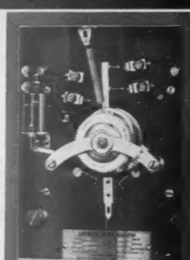

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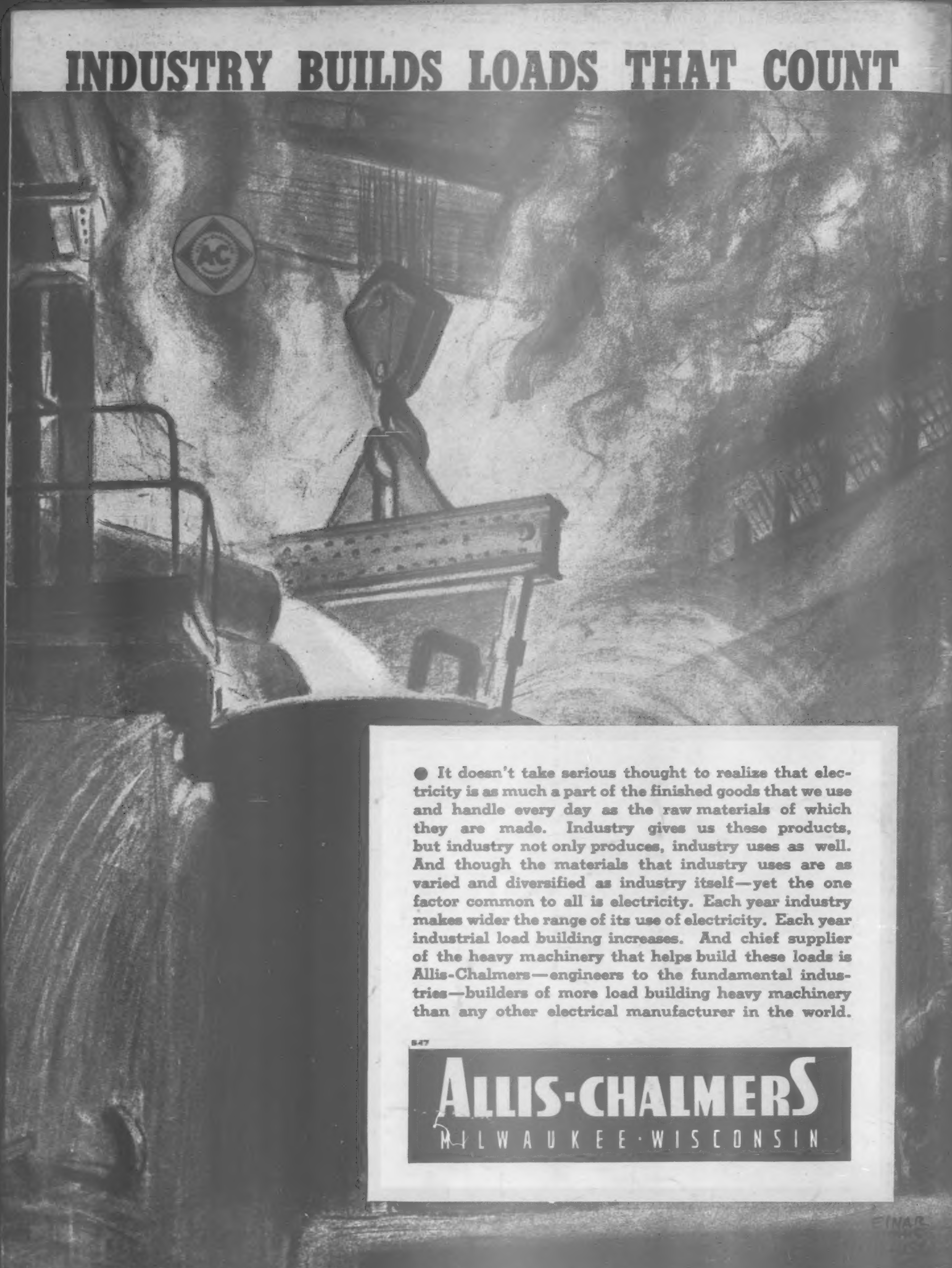
INDUSTRY BUILDS LOADS THAT COUNT
AC
● It doesn't take serious thought to realize that electricity is as much a part of the finished goods that we use and handle every day as the raw materials of which they are made. Industry gives us these products, but industry not only produces, industry uses as well. And though the materials that industry uses are as varied and diversified as industry itself—yet the one factor common to all is electricity. Each year industry makes wider the range of its use of electricity. Each year industrial load building increases. And chief supplier of the heavy machinery that helps build these loads is Allis-Chalmers—engineers to the fundamental industries—builders of more load building heavy machinery than any other electrical manufacturer in the world.
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